METHOD OF AND SYSTEM FOR IMAGE PROCESSING AND RECORDING MEDIUM

FOR CARRYING OUT THE METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a method of and system for carrying out an image processing such as a processing for enhancing a predetermined frequency component of an image signal. This invention further relates to a computer-readable recording medium loaded with program for causing a computer to perform the image processing in accordance with the method.

Description of the Related Art

We have proposed various image processing methods and systems for improving diagnostic performance of a radiation image by carrying out on a radiation image signal representing the radiation image, for instance, a frequency enhancement processing or a dynamic range compression processing by use of an unsharp mask image signal (will be referred to as "unsharp image signal", hereinbelow). See, for instance, Japanese Unexamined Patent Publication Nos. 55(1980)-163472, 55(1980)-87953, 3(1991)-222577, 10(1998)-75395, and 10(1998)-171983. For example, in the frequency enhancement processing, a predetermined spatial frequency component of an original image signal is enhanced by subtracting an unsharp image signal S_{us} from the original image signal S_{orig}, and adding the remainder multiplied by a coefficient of enhancement β to the

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original image signal S_{orig}. This is represented by the following formula (1).

$$S_{proc}=S_{org}+\beta\times(S_{org}-S_{us}) \qquad (1)$$

wherein S_{proc} is a frequency-enhanced image signal, S_{org} is an original image signal, S_{us} is an unsharp image signal and β is a coefficient of enhancement.

Further, in Japanese Unexamined Patent Publication No. 10(1998)-75395, there is disclosed a method of preventing generation of an artifact in the frequency-enhanced image signal by adjusting the frequency response characteristic of the add signal to be added to the original image signal. In this method, a plurality of unsharp image signals, which are different from each other in frequency response characteristic, that is, in sharpness, are prepared, differences between two of the original image signal and the unsharp image signals are taken, thereby making a plurality of band-limited signals respectively representing frequency components in limited frequency bands of the original image signal, the band-limited signals thus obtained are transformed into signals of desired values by use of different transformation functions, and the add signal is made by adding up the suppressed band-limited signals. This is represented, for instance, by the following formulae (2).

$$S_{proc}=S_{org}+\beta(S_{org}) \times F_{usm}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\cdots\ S_{us}N)$$

$$F_{usm}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\cdots\ S_{us}N)$$

$$=f_1(S_{org}-S_{us}1)+f_2(S_{us}1-S_{us}2)+\cdots$$

$$+\ f_k(S_{us}k-1-S_{us}k)+\ \cdots\ +f_N(S_{us}N-1-S_{us}N) \qquad (2)$$

wherein S_{proc} is a processed image signal, S_{org} is an original image signal, $S_{us}k$ (k=1 to N) is an unsharp image signal, f_k(k=1 to N) is a transformation function, and $\beta(S_{org})$ is a coefficient of enhancement determined on the basis of the original image signal.

Further, in Japanese Unexamined Patent Publication No. 10(1998)-171983, there is disclosed a method of preventing generation of an artifact in the processed signal when both the frequency enhancement processing and the dynamic range compression processing are to be carried out. In this method, a plurality of band-limited signals are made in the manner described above, a high frequency component signal representing high frequency components of the original image signal and a low frequency component signal representing low frequency components of the original image signal are obtained on the basis of the band-limited signals, and the frequency enhancement processing and the dynamic range compression processing are carried out by adding the high frequency component signal and the low frequency component signal to the original image signal. This is represented, for instance, by the following formulae (3).

$$S_{proc}=S_{org}+\beta(S_{org}) \times F_{usm}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\cdots\ S_{us}N)$$
$$+ D\{S_{org}-F_{drc}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\cdots\ S_{us}N)\}$$

$$F_{usm}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\cdots\ S_{us}N)$$
$$=\{f_{u1}(S_{org}-S_{us}1)+f_{u2}(S_{us}1-S_{us}2)+ \cdots$$
$$+ f_{uk}(S_{us}k-1-S_{us}k)+ \cdots +f_{uN}(S_{us}N-1-S_{us}N)$$

$$F_{drc}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\cdots\ S_{us}N)$$

$$=\{f_{d1}(S_{org}-S_{us}1)+f_{d2}(S_{us}1-S_{us}2)+\cdots$$

$$+\ f_{dk}(S_{us}k-1-S_{us}k)+\ \cdots\ +f_{dN}(S_{us}N-1-S_{us}N)$$

$$(3)$$

wherein S_{proc} is a processed image signal, S_{org} is an original image signal, $S_{us}k$ (k=1 to N) are unsharp image signals, f_{uk}(k=1 to N) are transformation functions for obtaining the high frequency component signal, f_{dk}(k=1 to N) is a transformation function for obtaining the low frequency component signal, $\beta(S_{org})$ is a coefficient of enhancement determined on the basis of the original image signal, and $D\{S_{org}-F_{drc}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\ S_{us}N)\}$ is a coefficient of dynamic range compression determined on the basis of the low frequency component signal, D being a function for transforming $D\{S_{org}-F_{drc}(S_{org},\ S_{us}1,\ S_{us}2,\ \cdots\ S_{us}N)\}$.

In the frequency enhancement processing and the dynamic range compression processing (will be representatively referred to "as the transformation processing", hereinbelow), the frequency response characteristic of the add signal to be added to the original image signal can be adjusted by changing the definition of the transformation functions and the like for transforming the band-limited signals. Accordingly, a processed image signal having a desired frequency response characteristic, e.g., suitable for preventing generation of an artifact, can be obtained by properly defining the transformation functions. However, it is not easy to know how to define the transformation functions in order to obtain a desired result. Therefore, there has been proposed, in Japanese

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Unexamined Patent Publication No. 10(1998)-63838, a method in which a processed image signal having a desired frequency response characteristic is easily obtained by designating a desired frequency response characteristic for a processed image

5   signal and determining parameters for defining the transformation functions (this parameter will be referred to as "transformation function defining parameter", hereinbelow) on the basis of the designated frequency response characteristic.

10   The unsharp image signals used in the aforesaid transformation processing are made by thinning picture elements by filtering picture elements of the original image signal at predetermined intervals and interpolating like number of picture elements. As the filtering processing, a processing for

15   removing high frequency components from the original image signal by use of a low-pass filter, more specifically a processing for calculating an average or a weighted average of the values of picture elements in the filter, has been carried out. In the filtering processing carried out in order to obtain

20   a plurality of unsharp image signals in Japanese Unexamined Patent Publication No. 10(1998)-75395 or the like, the unsharp image signals are obtained by filtering the original image signal to obtain an image signal with less picture elements, further filtering the image signal with less picture elements, and

25   interpolating picture elements into the image signal with less picture elements obtained at each filtering stage so that the

number of the picture elements in the image signal becomes equal to that in the original image signal.

Each unsharp image signal is thus made on the basis of the original image signal, which is obtained by reading an original image at a predetermined read density by use of an image reader and digitizing the image signal thus obtained into a digital image signal which can reproduce an image at a predetermined picture element density. It has been known that frequency components lower than a certain frequency determined according to the picture element density (a Nyquist rate) can be correctly reproduced when a digitized image signal is to be reproduced as a printed output. That is, since being determined taking into account the level of image quality required upon reproduction, the read density, i.e., the picture element density is not constant.

For example, in a radiation image read-out and reproducing system, where a radiation image of a human body recorded on a stimulable phosphor sheet is read out as a digital image by scanning the stimulable phosphor sheet with a laser beam, the read density or the picture element density varies depending on the size of the stimulable phosphor sheet and can be freely set by an user.

When image signals different in picture element density or Nyquist frequency are subjected to the same filtering processing using the same low-pass filters and then to the same interpolation, the frequency characteristics of the obtained

band-limited signals (more specifically the frequency bands of the obtained band-limited signals) differ depending on the picture element density. This means that, for instance, when a pair of image signals having different picture element densities are obtained by reading an original image at different read densities, and a frequency enhancement processing or a dynamic range compression processing is carried out on the image signals by use of band-limited signals obtained on the basis of the same unsharp image signals, the enhanced frequency band or the compressed frequency band differ between the two original image signals.

In order to overcome this problem, there has been proposed, in Japanese Unexamined Patent Publication No. 10(1998)-63837, a method in which unsharp image signal are obtained by selecting coefficients of filter from a list of coefficients of filter according to information on the picture element density of the original image signal and filtering the original image signal by use of filters of the selected coefficients of filter. That is, when original image signals, for instance, respectively read at read densities of 5 lines/mm and 6.7 limes/mm are filtered by use of the same low-pass filter, the obtained two band-limited signals differ from each other in frequency band. However in the method proposed by the above identified Japanese Unexamined Patent Publication, the two original image signals are filtered by different low-pass filters and accordingly the obtained two band-limited signals can be substantially the same in frequency

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band. Accordingly, unsharp image signals of the same frequency bands can be obtained irrespective of the picture element density of the original image signals, whereby band-limited signals of the same frequency characteristics can be made and a desired transformation processing, e.g., the aforesaid frequency enhancement processing, can be constantly carried out in the same manner.

However, since energy of a band-limited image represented by a band-limited signal, that is, the peak value of response of a band-limited signal, varies depending on the picture element density, the method disclosed in Japanese Unexamined Patent Publication No. 10(1998)-63837 cannot make constant the response of the band-limited signals in the same frequency band irrespective of the picture element density though can make the frequency bands of the band-limited signals equal to each other. Accordingly, even if a processing is carried out to enhance a band-limited signal in a particular frequency band, the response characteristic of the enhanced band-limited signal delicately varies depending on the picture element density.

In the image processing system described above, there is sometimes input an object original image signal (an original image signal to be processed) representing an image which differs in resolution from images which are normally processed by the image processing system. (The resolution of the images which are normally processed by the image processing system will be referred to as "the reference resolution", hereinbelow) In such

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a case, when the transformation processing such as the frequency

enhancement processing is carried out on the object original

image signal by use of the transformation functions which have

been determined for original image signals representing images

5   at the reference resolution, there is a fear that the frequency

response characteristic of the image reproduced on the basis

of the processed image signal obtained from the object original

image signal becomes different from that of the image reproduced

on the basis of the original image signal representing an image

10   at the reference resolution. This problem may be overcome, for

instance, by preparing a plurality of groups of transformation

functions and using one group of the transformation functions

according to the resolution of the image represented by the

object original image signal. However, this approach is

15   disadvantageous in that the number of the transformation

functions becomes too large and management of the transformation

functions becomes too troublesome.

Further, though there have been known, as formats for

compressing an original image signal, various formats such as

20   JPEG, GIF, TIFF and the like, there is recently proposed a format

in which an original image signal is hierarchically decomposed

by resolution into hierarchical data, and the hierarchical data

in each hierarchy is encoded and compressed.   In this

compression format, specifically, an original image signal is

25   decomposed by wavelet transformation or the like into a plurality

of hierarchical image signals, each having a resolution of $1/2^n$

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times that of the original image signal, and the hierarchical image signals are encoded in the hierarchical sequence and compressed into a single file.

The compression format has the following features.

5 (1) Since the image signal is not processed block by block unlike the DCT format employed in the conventional JPEG, artifact like block distortion is not generated.

(2) Since the image signals are hierarchically encoded, information on necessary resolutions has only to be transferred upon transfer of the image signals, which results in efficient image transfer.

(3) Since the image signal is decomposed into multiple resolutions, various image processing such as frequency enhancement processing can be relatively easily carried out.

15 (4) Since space decomposition and frequency decomposition can be simultaneously carried out by multiple resolution analysis, an orthogonal transformation can be carried out over a wide range on a low frequency region, which largely affects the encoding efficiency, whereas over a narrow region on a high frequency

20 region. Accordingly, even if quantization noise is generated around an edge of the image, spatial spread of the noise can be suppressed so that the noise becomes less apt to be recognized.

Further, there have been proposed various file formats such as a FlashPix file proposed by Eastman Kodak in which data

25 of different kinds can be stored in a single file. The aforesaid hierarchical image signals can be also stored in such a FlashPix

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standard file.

By decomposing an original image signal into multiple resolutions, it is possible to construct the original image signal by a plurality of hierarchical image signals, each having a resolution of $1/2^n$ times that of the original image signal. This makes it feasible to reconstruct an image on the basis of a part of the hierarchical image signals which is selected according to the image quality required by the output system. That is, when a high quality image is to be reproduced as in a printer, an image signal which can reproduce a high quality image equivalent to the original image in resolution can be obtained by reconstructing the image signal on the basis of hierarchical image signals up to that of the highest resolution. To the contrast, in the case of, for instance, a CRT which cannot reproduce an image in a quality so high as a printer, an image signal which can reproduce an image suitable for the CRT though not so high as the original image in resolution can be obtained by reconstructing the image signal on the basis of hierarchical image signals not including the highest resolution hierarchical image signal and enlarging or contracting the image signal, if necessary.

However since the hierarchical image signals each representing an image lower in resolution (such hierarchical image signals will be referred to as "lower hierarchical image signals" hereinbelow) than that represented by the original image signal differ from the original image signal in frequency

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response characteristic, if the transformation functions for the original image signal are employed as they are in frequency enhancement processing of the lower hierarchical image signals, there is a fear that an image signal which is different in frequency response characteristic from an image signal obtained by carrying out the frequency enhancement processing on the original image signal can be obtained. This may be overcome by preparing a number of transformation functions conforming to various resolutions and employing transformation functions according to the resolution of the image signal to be processed. However this approach is disadvantageous in that the number of transformation functions to be managed becomes too large and management of transformation functions becomes too troublesome. This problem occurs not only when carrying out frequency enhancement processing on image signals obtained by decomposing an original image signal into multiple resolutions but also when carrying out frequency enhancement processing on an image signal in order to reproduce an image lower than an original image signal.

Further, for example, a radiation image reproduced at pitches of 10 lines/mm by doubling and interpolating an original image signal read out from a stimulable phosphor sheet at a read density of 5 lines/mm is inferior in sharpness to a radiation image reproduced at pitches of 10 lines/mm on the basis of an original image signal read out from a stimulable phosphor sheet at a read density of 10 lines/mm though the sizes of images are

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the same. This is because high frequency components of the original image signal are weakened depending on the characteristic of the filter employed for changing the picture element density of the original image signal, that is, for contracting and interpolating the original image signal and the characteristic of the filter for doubling the contracted original image signal and because the former image is different from the latter image in frequency response characteristic. Further

when a low resolution image is reproduced on the basis of a hierarchical image signal obtained by decomposing an original image signal representing an original image into multiple resolutions, the obtained image becomes inferior to the original image in sharpness depending on the wavelet transformation functions employed in wavelet transformation. Further when a low resolution image is enlarged to the same size as the original image, high frequency components of the original image signal are weakened depending on the characteristic of the filter for enlargement and interpolation and the obtained image becomes inferior to the original image in sharpness. The same problem occurs also when the original image is to be enlarged or contracted to a desired size. Accordingly when the aforesaid frequency enhancement processing is carried out on an image signal representing an image less sharp than the original image, the obtained image becomes different in impression from an image obtained by carrying out the same frequency enhancement

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processing on the original image signal.

SUMMARY OF THE INVENTION

In view of the foregoing observations and description, the primary object of the present invention is to provide a method of and a system for image processing which can constantly carry out a desired transformation processing, e.g., a processing for enhancing a particular frequency component, so as to result in the same result irrespective of the picture element density of the original image signal.

Another object of the present invention is to provide a method of and a system for image processing which can constantly carry out frequency enhancement processing so as to result in the same result irrespective of the resolution of the image to be processed and without necessity of storing a large number of transformation functions.

Another object of the present invention is to provide a method of and a system for image processing which can constantly carry out frequency enhancement processing so as to result in the same result irrespective of the resolution of the image to be reproduced and without necessity of storing a large number of transformation functions.

Another object of the present invention is to provide a method of and system for image processing which can carry out frequency enhancement processing on an image which is different from an original image in picture element density and/or scale so that the frequency response characteristic of the obtained

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image becomes equivalent to that of the original image.

Still another object of the present invention is to provide a computer-readable recording medium loaded with program for causing a computer to perform the image processing in accordance with the method of the present invention.

In accordance with a first aspect of the present invention, there is provided an image processing method for obtaining a processed image signal from an original image signal representing an original image having a certain picture element density in which a plurality of intermediate image signals which are different in frequency band are made on the basis of the original image signal, a plurality of transformed image signals are obtained by carrying out a transformation processing on the respective intermediate image signals on the basis of respective transformation functions, and a processed image signal is obtained from the transformed image signals, wherein the improvement comprises the step of

defining said transformation functions by determining transformation function defining parameters for the transformation functions on the basis of the picture element density of the original image.

The "transformation processing" includes, for instance, a frequency enhancement processing represented by formulae (2) for enhancing a particular frequency component and a dynamic range compression processing represented by formulae (3) for reducing the contrast of the high density range and/or the low

density range, thereby narrowing the dynamic range which is the difference between the maximum density and the minimum density of the original image.

The "picture element density of the original image" may be either input by the operator or may be automatically obtained when the original image signal is processed. In the latter case, information on the picture element density is attached to the original image signal in advance. The "picture element density" may be, for instance, a value of resolution (e.g., in dpi) which represents the relation between the size of the original image and the sampling intervals for obtaining the original image signal as well as the read density at which a radiation image recorded on a stimulable phosphor sheet is read.

Further, the expression "transformation function defining parameters for the transformation functions are determined on the basis of the picture element density of the original image signal" means, for instance, to obtain the parameters by resolving relational expressions of the aforesaid plurality of intermediate image signals, a desired frequency response characteristic and the transformation function defining parameters as simultaneous equations taking the plurality of intermediate image signals and the desired frequency response characteristic as known values and the transformation function defining parameters as variables, or to determine the transformation function defining parameters by gradually changing the parameters while watching the image

reproduced on the basis of the processed image signal. As the

transformation functions, various functions such as linear

functions, non-linear functions, constants and the like can be

used.

5   It is preferred that said plurality of intermediate image

signals which are different in frequency band be made by carrying

out on the original image signal a filtering processing by use

of filters whose coefficients of filter are determined on the

basis of the picture element density of the original image,

10   thereby making a plurality of unsharp image signals which are

different in frequency response characteristic, making a

plurality of band-limited signals representing the signals in

the respective frequency bands of the original image signal on

the basis of the unsharp image signals and the original image

15   signal, and taking the band-limited signals as the intermediates

image signals.

The "unsharp image signals" are image signals which are

equivalent to the original image signal in the number of picture

elements but represent images which are lower in sharpness than

20   that represented by the original image signal. The unsharp

image signals are made by thinning picture elements by filtering

picture elements of the original image signal at predetermined

intervals, further thinning picture elements by filtering

picture elements of the thinned image signal, repeating these

25   procedures, and interpolating picture elements into the image

signal with less picture elements obtained at each filtering

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stage so that the number of the picture elements in the image signal becomes equal to that in the original image signal. The filtering processing is carried out by use of filters having coefficients of filter determined on the basis of the picture element densities, and is described in detail in the above identified Japanese patent publication, Japanese Unexamined Patent Publication No. 10(1998)-63837.

The "plurality of band-limited signals representing the signals in the respective frequency bands of the original image signal" may be made, for instance, by taking differences between unsharp image signals in adjacent frequency bands, differences between the original image signal and the respective unsharp image signals, or differences between any other combinations of the unsharp image signals.

In accordance with a second aspect of the present invention, there is provided an image processing system for obtaining a processed image signal from an original image signal representing an original image having a certain picture element density comprising an intermediate image signal making means which makes a plurality of intermediate image signals which are different in frequency band on the basis of the original image signal, and a transformation means which obtains a plurality of transformed image signals by carrying out a transformation processing on the respective intermediate image signals on the basis of respective transformation functions, and obtains a processed image signal from the transformed image signals,

wherein the improvement comprises that

a transformation function defining means which determines transformation function defining parameters for the transformation functions on the basis of the picture element density of the original image and defines the transformation functions.

It is preferred that the intermediate image signal making means comprises an unsharp image signal making means which makes a plurality of unsharp image signals which are different in frequency response characteristic by carrying out on the original image signal a filtering processing by use of filters whose coefficients of filter are determined on the basis of the picture element density of the original image, and a band-limited signal making means which makes, as the intermediates image signals, a plurality of band-limited signals representing the signals in the respective frequency bands of the original image signal on the basis of the unsharp image signals and the original image signal.

In accordance with a third aspect of the present invention, there is provided a computer-readable recording medium loaded with program for causing a computer to perform the image processing method in accordance with the first aspect of the present invention.

In accordance with the method and the system of the first and second aspects of the present invention, since the transformation function defining parameters are obtained on the

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basis of the picture element density of the original image and the transformation processing is carried out according to the transformation functions defined by the transformation function defining parameters, the parameters can be set so that the intermediate image signals different in frequency band are transformed into transformed image signals which are the same in frequency response characteristic irrespective of the picture element density of the original image, whereby the transformation processing can be carried out so that a processed image signal can reproduce an image having a constant frequency response characteristic without affected by the picture element density of the original image.

In accordance with a fourth aspect of the present invention, there is provided an image processing method for obtaining a processed image signal from an original image signal representing an original image at a certain resolution, in which a plurality of intermediate image signals which are different in frequency band are made on the basis of the original image signal, a plurality of transformed image signals are obtained by carrying out a transformation processing on the respective intermediate image signals on the basis of respective transformation functions, and a processed image signal is obtained from the transformed image signals, wherein the improvement comprises that

the transformation functions for processing the intermediate image signals obtained from an object original

image signal to be processed are determined by correcting, according to the resolution of the object original image signal, reference transformation functions for transforming the intermediate image signals obtained from a reference original

5   image signal representing an image having a reference resolution, the reference transformation functions having been determined and stored in advance.

The "transformation processing" includes, for instance, a frequency enhancement processing represented by formulae (2)

10   for enhancing a particular frequency component and a dynamic range compression processing represented by formula (3) for reducing the contrast of the high density range and/or the low density range, thereby narrowing the dynamic range which is the difference between the maximum density and the minimum density

15   of the original image.

The "resolution of the object original image signal" may be either input by the operator or automatically obtained when the original image signal is processed. In the latter case, information on the resolution is attached to the original image

20   signal in advance. The "resolution" may be, for instance, a value of resolution (e.g., in dpi) which represents the relation between the size of the original image and the sampling intervals for obtaining the original image signal as well as the read density at which a radiation image recorded on a stimulable

25   phosphor sheet is read.

It is preferred that said plurality of intermediate image

signals which are different in frequency band be made by carrying out on the original image signal a filtering processing by use of filters having predetermined coefficients of filter, thereby making a plurality of unsharp image signals which are different in frequency response characteristic, making a plurality of band-limited signals representing the signals in the respective frequency bands of the original image signal on the basis of the unsharp image signals and the original image signal, and taking the band-limited signals as the intermediates image signals.

The "unsharp image signals" are image signals which are equivalent to the original image signal in the number of picture elements but represent images which are lower in sharpness than that represented by the original image signal. The unsharp image signals are made by thinning picture elements by filtering picture elements of the original image signal at predetermined intervals, further thinning picture elements by filtering picture elements of the thinned image signal, repeating these procedures, and interpolating picture elements into the image signal with less picture elements obtained at each filtering stage so that the number of the picture elements in the image signal becomes equal to that in the original image signal. The filtering processing is carried out by use of filters having coefficients of filter determined on the basis of the picture element densities, and is described in detail in the above identified Japanese patent publication, Japanese Unexamined

Patent Publication No. 10(1998)-63837.

The "plurality of band-limited signals representing the signals in the respective frequency bands of the original image signal" may be made, for instance, by taking differences between unsharp image signals in adjacent frequency bands, differences between the original image signal and the respective unsharp image signals, or differences between any other combinations of the unsharp image signals.

In accordance with a fifth aspect of the present invention, there is provided an image processing system comprising an intermediate image signal making means which makes a plurality of intermediate image signals which are different in frequency band on the basis of an original image signal representing an original image having a predetermined resolution, and a transformation means which obtains a plurality of transformed image signals by carrying out a transformation processing on the respective intermediate image signals on the basis of respective transformation functions, and obtains a processed image signal from the transformed image signals, wherein the improvement comprises that

a transformation function calculating means which calculates the transformation functions for processing the intermediate image signals obtained from an object original image signal to be processed by correcting, according to the resolution of the object original image signal, reference transformation functions for transforming the intermediate

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image signals obtained from a reference original image signal having a reference resolution, the reference transformation functions having been determined and stored in advance.

It is preferred that the intermediate image signal making means comprises an unsharp image signal making means which makes a plurality of unsharp image signals which are different in frequency response characteristic by carrying out on the original image signal a filtering processing by use of filters whose coefficients of filter are determined on the basis of the resolution of the original image signal, and a band-limited signal making means which makes, as the intermediates image signals, a plurality of band-limited signals representing the signals in the respective frequency bands of the original image signal on the basis of the unsharp image signals and the original image signal.

In accordance with a sixth aspect of the present invention, there is provided a computer-readable recording medium loaded with program for causing a computer to perform the image processing method in accordance with the fourth aspect of the present invention.

In accordance with the method and the system of the fourth and fifth aspects of the present invention, since the transformation functions for transforming the intermediate image signals obtained from an object original image signal representing an image whose resolution is different from the reference resolution are obtained by correcting the reference

transformation functions according to the resolution of the object original image signal, the transformation functions can be set so that the intermediate image signals are transformed into transformed image signals which are the same in frequency response characteristics irrespective of the picture element density of the original image signal, whereby the transformation processing can be carried out so that a processed image signal can reproduce an image having a constant frequency response characteristic without affected by the resolution of the original image signal.

Further, since the transformation functions for original image signals having resolutions different from the reference resolution are obtained by correcting the reference transformation functions, it is not necessary to prepare a plurality of transformation functions for various resolutions, whereby trouble to manage a plurality of transformation functions can be saved.

In accordance with a seventh aspect of the present invention, there is provided an image processing method for obtaining a processed image signal from an original image signal representing an original image having a certain resolution, in which a plurality of intermediate image signals which are different in frequency band are made on the basis of the original image signal, a plurality of transformed image signals are obtained by carrying out a transformation processing on the respective intermediate image signals on the basis of

transformation functions which are set according to the frequency bands of the respective intermediate image signals, and a processed image signal is obtained from the transformed image signals, wherein the improvement comprises the steps of

preparing reference transformation functions for transforming the intermediate image signals obtained from a reference original image signal representing a reference original image having a reference resolution which are set according to the frequency bands of the respective intermediate image signals, and, when an object original image signal to be processed represents an original image having a resolution lower than the reference resolution, setting the transformation functions for transforming the intermediate image signals obtained from the object original image signal to be equal to the respective reference transformation functions for the intermediate image signals in the frequency bands not higher than the frequency band corresponding to the resolution of the original image represented by the object original image signal.

The "transformation functions which are set according to the frequency bands of the respective intermediate image signals" are six in number when the intermediate image signals are in six frequency bands. The transformation functions may be constants. The expression "the respective reference transformation functions for the intermediate image signals in the frequency bands not higher than the frequency band corresponding to the resolution of the original image

represented by the object original image signal" means, for instance, when the resolution of the original image represented by the object original image signal is $1/2^k$ times that of the reference resolution, the reference transformation functions for the k-th intermediate image signal as numbered from the high frequency side and those in the frequency bands lower than the k-th intermediate image signals. For example, when six intermediate image signals are obtained from the reference original image signal and six transformation functions (f_1 to f_6, f_1 being in the highest frequency band) are set for the respective image intermediate signals with the resolution of the original image represented by the object original image signal being 1/2 of that of the reference original image, "the respective reference transformation functions for the intermediate image signals in the frequency bands not higher than the frequency band corresponding to the resolution of the original image represented by the object original image signal" are the transformation functions f_2 to f_6.

In the image processing method in accordance with the seventh aspect of the present invention, it is preferred that said plurality of intermediate image signals be band-limited signals which are made by making, on the basis of the original image signal (the reference original image signal or the object original image signal), a plurality of unsharp image signals which are different in frequency response characteristic, and making a plurality of band-limited signals representing the

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signals in the respective frequency bands of the original image signal on the basis of the unsharp image signals and the original image signal.

The "unsharp image signals" are image signals which are equivalent to the original image signal in the number of picture elements but represent images which are lower in sharpness than that represented by the original image signal. The unsharp image signals are made by thinning picture elements by filtering picture elements of the original image signal at predetermined intervals, further thinning picture elements by filtering picture elements of the thinned image signal, repeating these procedures to obtain a plurality of low resolution image signals respectively representing images whose resolutions are $1/2^n$ of that of the image represented by the reference original image signal, and interpolating picture elements into the low resolution image signal with less picture elements obtained at each filtering stage so that the number of the picture elements in the image signal becomes equal to that in the original image signal.

The "plurality of band-limited signals representing the signals in the respective frequency bands of the original image signal" may be made, for instance, by taking differences between unsharp image signals in adjacent frequency bands, differences between the original image signal and the respective unsharp image signals, or differences between any other combinations of the unsharp image signals.

Further, it is preferred that information on the resolution of the original image represented by the object original image signal be obtained and the step of setting the transformation functions for transforming the intermediate image signals obtained from the object original image signal be executed on the basis of the information.

The resolution information may be input as a value by the operator through a keyboard or by the operator selecting a value from a plurality of resolutions displayed on a control screen. Further, the resolution information may be attached to the object original image signal and may be detected by the image processing system. The resolution information may be input in any way so long as the system can recognize the resolution of the original image represented by the object original image signal.

In the image processing method in accordance with the seventh aspect of the present invention, when the original image represented by the object original image signal to be processed has a resolution lower than the reference resolution, the transformation functions for transforming the intermediate image signals obtained from the object original image signal are set to be equal to the respective reference transformation functions for the intermediate image signals in the frequency bands not higher than the frequency band corresponding to the resolution of the original image represented by the object original image signal. When the resolution of the original image represented by the object original image signal is $1/2^n$

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of the resolution of the reference original image represented by the reference original image signal, the peak frequencies of the intermediate image signals obtained from the object original image signal are the same as those of a part of the reference intermediate image signals (obtained from the reference original image signal) which are in frequency bands not higher than the frequency band corresponding to the resolution of the original image represented by the object original image signal. Accordingly, when the intermediate image signals obtained from the object original image signal are transformed on the basis of the reference transformation functions for the part of the reference intermediate image signals which are in frequency bands not higher than the frequency band corresponding to the resolution of the original image represented by the object original image signal, the obtained transformed image signals are substantially the same as the reference transformed image signals in frequency response characteristics. The processed image signal can reproduce an image which is substantially the same in frequency response characteristic as an image reproduced on the basis of the processed image signal obtained from the reference original image signal. Thus in accordance with the image processing method of the seventh aspect of the present invention, a processed image signal which can reproduce an image which is substantially constant in frequency response characteristic can be obtained irrespective of the resolution of the object original

image signal.

Further, since the transformation functions for obtaining the processed image signal from the reference original image signal are employed to obtain the processed image signal from the object original image signal, it is not necessary to prepare a plurality of transformation functions for various resolutions, whereby the system can be simplified in structure and trouble to manage a plurality of transformation functions can be saved.

In accordance with an eighth aspect of the present invention, there is provided an image processing system for carrying out the image processing method in accordance with the seventh aspect of the present invention.

In accordance with a ninth aspect of the present invention, there is provided a computer-readable recording medium loaded with program for causing a computer to perform the image processing method in accordance with the seventh aspect of the present invention.

In accordance with a tenth aspect of the present invention, there is provided an image processing method for making a contraction-processed image signal representing an image having a desired resolution lower than that of an image represented by a reference processed image signal which is obtained by making first to n-th reference low resolution image signals from a reference original image signal representing a reference original image, the reference low resolution image signals being different from each other in frequency band and respectively

representing images whose resolutions are $1/2^k$ (k=1 to n) of the resolution of the reference original image signal; making reference low-resolution band-limited signals on the basis of the reference low resolution image signals; obtaining a plurality of reference transformed image signals by carrying out a predetermined transformation processing on the reference low resolution band-limited signals on the basis of a plurality of reference transformation functions which are set according to the respective frequency bands of the reference low resolution band-limited signals; and carrying out a predetermined processing on the reference transformed image signals, the image processing method characterized by the steps of

taking as an original image signal one of said first to n-th reference low resolution image signals representing an image whose resolution is the closest to said desired resolution in the images represented by the reference low resolution image signals; making first to m-th low resolution image signals from the original image signal, the low resolution image signals being different from each other in frequency band and respectively representing images whose resolutions are $1/2^{k'}$ (k'=1 to m) of the resolution of the original image signal; making a low-resolution band-limited signals on the basis of the low resolution image signals; obtaining a plurality of transformed image signals by carrying out said predetermined transformation processing on the low resolution band-limited signals on the basis of a part of said reference transformation functions which

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are set for the respective frequency bands of the reference low resolution band-limited signals not higher than the frequency band corresponding to the resolution closest to said desired resolution; carrying out said predetermined processing on the transformed image signals, thereby obtaining an intermediate processed image signal; enlarging or contracting the intermediate processed image so that the resolution of the image represented by the intermediate processed image signal becomes equal to the desired resolution; and taking the enlarged or contracted intermediate processed image signal as the contraction-processed image signal.

In the image processing method in accordance with the tenth aspect of the present invention, out of the reference low resolution image signals obtained from the reference original image signal, a reference low resolution image signal representing an image whose resolution is closest to the desired resolution is taken as an object original image signal for obtaining a contraction-processed image signal, and a plurality of low resolution image signals are obtained from the object original image signal. Accordingly, the peak frequencies of the low resolution band-limited signals obtained from the object original image signal are the same as those of a part of the reference low resolution band-limited signals which are in frequency bands not higher than the frequency band corresponding to the resolution closest to the desired resolution. Accordingly, when the low resolution band-limited signals

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obtained from the object original image signal are transformed on the basis of the reference transformation functions for the part of the reference low resolution band-limited signals which are in frequency bands not higher than the frequency band corresponding to the resolution closest to the desired resolution, the obtained transformed image signals are substantially the same as the reference transformed image signals in frequency response characteristics. The contraction-processed image signal obtained by enlarging or contracting the intermediate processed image signal obtained from the transformed image signals so that the resolution of the image represented by the intermediate processed image signal becomes equal to the desired resolution can reproduce an image which is substantially the same in frequency response characteristic as an image reproduced on the basis of the reference processed image signal. Thus in accordance with the image processing method of the tenth aspect of the present invention, a contraction-processed image signal which can reproduce an image which is substantially constant in frequency response characteristic can be obtained irrespective of the resolution of the image to be reproduced.

Further, since the transformation functions for obtaining the reference processed image signal are employed to obtain the contraction-processed image signal, it is not necessary to prepare a plurality of transformation functions for various resolutions, whereby the system can be simplified in structure

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and trouble to manage a plurality of transformation functions can be saved.

In accordance with an eleventh aspect of the present invention, there is provided an image processing system for carrying out the image processing method in accordance with the tenth aspect of the present invention.

In accordance with a twelfth aspect of the present invention, there is provided a computer-readable recording medium loaded with program for causing a computer to perform the image processing method in accordance with the tenth aspect of the present invention.

In accordance with a thirteenth aspect of the present invention, there is provided an image processing method for obtaining a processed image signal from an original image signal representing an original image having a certain picture element density, in which a plurality of intermediate image signals which are different in frequency band are made on the basis of the original image signal, a plurality of transformed image signals are obtained by carrying out a transformation processing on the respective intermediate image signals on the basis of respective transformation functions, and a processed image signal in which a predetermined frequency component is enhanced is obtained from the transformed image signals, wherein the improvement comprises that

when an object original image signal to be processed is a contracted image signal obtained by carrying out a picture

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element density transformation processing on a reference original image signal representing an image having a reference picture element density, the transformation functions for processing the intermediate image signals obtained from the object original image signal are determined by correcting, according to the characteristic of the picture element density transformation processing, reference transformation functions for transforming the intermediate image signals obtained from the reference original image so that the frequency response characteristic of a desired frequency component of the processed image signal obtained from the object original image signal becomes equivalent to that of the processed image signal obtained from the reference original image signal, the reference transformation functions having been determined and stored in advance.

It is preferred that when the processed image signal obtained from the contracted image signal is enlarged at a magnification, the transformation functions for processing the intermediate image signals obtained from the object original image signal be determined by correcting the reference transformation functions according to the characteristic of the picture element density transformation processing and the characteristic of the enlargement.

In accordance with a fourteenth aspect of the present invention, there is provided an image processing method for obtaining a processed image signal from an original image signal

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representing an original image, in which a plurality of intermediate image signals which are different in frequency band are made on the basis of the original image signal, a plurality of transformed image signals are obtained by carrying out a transformation processing on the respective intermediate image signals on the basis of respective transformation functions, and a processed image signal in which a predetermined frequency component is enhanced is obtained from the transformed image signals, wherein the improvement comprises that

when an enlarged processed image signal is to be obtained by enlarging the processed image signal at a desired magnification by carrying out an enlargement transformation on the processed image signal, the transformation functions for transforming the respective intermediate image signals are corrected according to the characteristic of the enlargement transformation so that the frequency response characteristic of a desired frequency component of the enlarged processed image signal becomes a predetermined frequency response characteristic.

In the image processing methods in accordance with the thirteenth and fourteenth aspects of the present invention, it is preferred that said plurality of intermediate image signals be band-limited signals which are made by making, on the basis of the original image signal, a plurality of unsharp image signals which are different in frequency response characteristic, and making a plurality of band-limited signals

representing the signals in the respective frequency bands of the original image signal on the basis of the unsharp image signals and the original image signal.

In accordance with fifteenth and sixteenth aspects of the present invention, there are provided image processing systems for carrying out the image processing methods in accordance with the thirteenth and fourteenth aspects of the present invention.

In accordance with seventeenth and eighteenth aspects of the present invention, there is provided a computer-readable recording medium loaded with program for causing a computer to perform the image processing methods in accordance with the thirteenth and fourteenth aspects of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic block diagram showing the arrangement of an image processing system in accordance with a first embodiment of the present invention,

Figure 2 is a schematic block diagram showing the arrangement of the unsharp image signal making means employed in the image processing system shown in Figure 1,

Figures 3A and 3B are views showing examples of the filter to be used in the filtering processing,

Figure 4 shows in detail the low-resolution image signal making processing,

Figure 5 is a view showing an example of the filter employed in the interpolation/enlargement processing,

Figure 6 is a view showing system for executing a frequency

enhancement processing as a non-linear processing,

Figure 7 shows the frequency response characteristics of band-limited signals obtained by carrying out, on an original image signal at a picture element density of 10 lines/mm, the filtering processing using the one-dimensional filter shown in Figure 3A,

Figure 8 shows the frequency response characteristics of band-limited signals obtained by carrying out, on an original image signal at a picture element density of 6.7 lines/mm, the filtering processing using the one-dimensional filter shown in Figure 3B,

Figure 9 shows the frequency response characteristics of band-limited signals obtained by carrying out, on an original image signal at a picture element density of 5 lines/mm, the filtering processing using the one-dimensional filter shown in Figure 3A,

Figure 10 is a schematic block diagram showing the structure of the transformation function defining means,

Figure 11 is a view showing the frequency response characteristic of the processed image signal obtained by processing the band-limited signals obtained from an original image signal at 10 lines/mm by the image processing system of the first embodiment,

Figure 12 is a view showing the frequency response characteristic of the processed image signal obtained by processing the band-limited signals obtained from an original

image signal at 6.7 lines/mm by the image processing system of the first embodiment,

Figure 13 is a view showing the frequency response characteristic of the processed image signal obtained by processing the band-limited signals obtained from an original image signal at 5 lines/mm by the image processing system of the first embodiment,

Figure 14 is a view showing an example of the user interface for designating the frequency response characteristics,

Figure 15 is a flow chart for illustrating operation of the image processing system of the first embodiment,

Figure 16 is a view showing system for executing a frequency enhancement processing and a dynamic range compression processing as a non-linear processing in an image processing system in accordance with a second embodiment of the present invention,

Figure 17 is a view showing an example of the transformation functions used in the first transformation section in the second embodiment,

Figure 18 is a view showing another example of the transformation functions used in the first transformation section in the second embodiment,

Figure 19 is a view showing an example of the transformation functions used in the second transformation section in the second embodiment,

Figure 20 is a view showing the frequency response

characteristic of the processed image signal S_{proc} obtained by processing an original image signal at 10 lines/mm in the image processing system of the second embodiment,

Figure 21 is a view showing the frequency response characteristic of the processed image signal S_{proc} obtained by processing an original image signal at 6.7 lines/mm in the image processing system of the second embodiment,

Figure 22 is a view showing the frequency response characteristic of the processed image signal S_{proc} obtained by processing an original image signal at 5 lines/mm in the image processing system of the second embodiment,

Figure 23 is a schematic block diagram showing the arrangement of an image processing system in accordance with a third embodiment of the present invention,

Figure 24 is a view showing the frequency response characteristics of the band-limited signals obtained from an original image signal S_{org} having a picture element density of 10 lines/mm,

Figure 25 is a view showing the frequency response characteristic of the processed image signal S_{proc} obtained by carrying out the frequency enhancement processing by use of the transformation functions shown in table 3 on the original image signal S_{org} at 10 lines/mm (solid line) and that of the processed image signal S_{proc} obtained by carrying out the frequency enhancement processing by use of the transformation functions shown in table 3 on the original image signal S_{org} at 300dpi (broken

line),

Figure 26 is a view showing the frequency response characteristics of the band-limited signals obtained from an original image signal at 300dpi,

Figure 27 is a view showing the frequency response characteristic of the processed image signal S_{proc} obtained by processing an original image signal at 300dpi by the image processing of the third embodiment of the present invention,

Figure 28 is a flow chart for illustrating operation of the image processing system of the third embodiment,

Figures 29A and 29B are views for illustrating different manners for selecting a reference picture element density,

Figure 30 is a view showing the relation between the number of the band-limited signals and the resolution,

Figure 31 is a view showing the frequency response characteristics of the band-limited signals obtained from an original image signal at 200dpi,

Figure 32 shows the frequency response characteristics of the processed image signal S_{proc} obtained by processing the original image signal S_{org} at 200dpi by use of the reference transformation functions (broken line) and the processed image signal $S_{proc}0$ obtained by processing the reference original image signal $S_{org}0$ at the reference picture element density by use of the reference transformation functions (solid line),

Figure 33 is a view showing the relation between the response X1[Fi] and the function X1[i],

Figure 34 is a view showing the relation between the functions $X1[i]$, and $Z1[i]$,

Figure 35 is a view showing a system for executing a frequency enhancement processing and a dynamic range compression processing as a transformation processing in an image processing system in accordance with a fifth embodiment of the present invention,

Figure 36 is a view showing an example of the transformation functions used in the first transformation section in the fifth embodiment,

Figure 37 is a view showing another example of the transformation functions used in the first transformation section in the fifth embodiment,

Figure 38 is a view showing an example of the transformation functions used in the second transformation section in the fifth embodiment,

Figure 39A is a view showing the frequency response characteristic of the reference processed image signal obtained by transforming the band-limited signals from the reference image signal (having a picture element density of 5 lines/mm) by use of reference transformation functions which are set so that relatively low frequency components are enhanced and the frequency response characteristic of the processed image signal obtained by transforming the band-limited signals from the original image signal to be processed by use of the transformation functions which are obtained by correcting the

reference transformation functions according to the picture element density (4 lines/mm) of the original image signal to be processed so that the frequency response characteristic of the processed image signal conforms to that of the reference

5   processed image signal in frequency bands not lower than 1/2 of the Nyquist frequency of the original image signal to be processed,

Figure 39B is a view showing the frequency response characteristic of the reference processed image signal obtained

10   by transforming the band-limited signals from the reference image signal (having a picture element density of 5 lines/mm) by use of reference transformation functions which are set so that relatively high frequency components are enhanced and the frequency response characteristic of the processed image signal

15   obtained by transforming the band-limited signals from the original image signal to be processed by use of the transformation functions which are obtained by correcting the reference transformation functions according to the picture element density (4 lines/mm) of the original image signal to

20   be processed so that the frequency response characteristic of the processed image signal conforms to that of the reference processed image signal in frequency bands not lower than 1/2 of the Nyquist frequency of the original image signal to be processed,

25   Figure 40 is a schematic block diagram showing the arrangement of an image processing system in accordance with

a sixth embodiment of the present invention,

Figures 41A to 41C are views for illustrating encoding the hierarchical image signals,

Figure 42 is a schematic block diagram showing the arrangement of the unsharp image signal making means employed in the image processing system shown in Figure 40,

Figure 43 is a view showing an example of the filter to be used in the filtering processing,

Figure 44 shows in detail the low-resolution image signal making processing,

Figure 45 is a view showing an example of the filter employed in the interpolation/enlargement processing,

Figure 46 is a view showing system for executing a frequency enhancement processing,

Figure 47 shows the frequency response characteristics of band-limited signals obtained from the reference original image signal,

Figure 48 shows the frequency response characteristics of band-limited signals obtained from low frequency original image signal having a resolution of 1/2 of that of the reference original image signal,

Figure 49 shows the frequency response characteristics of band-limited signals obtained from low frequency original image signal having a resolution of 1/4 of that of the reference original image signal,

Figure 50 shows the frequency response characteristics

of band-limited signals obtained from low frequency original image signal having a resolution of 1/8 of that of the reference original image signal,

Figure 51 shows the frequency response characteristics of band-limited signals obtained from low frequency original image signal having a resolution of 1/16 of that of the reference original image signal,

Figure 52 is a flow chart showing operation of the image processing system in accordance a sixth embodiment of the present invention,

Figure 53 is a view showing correspondence between the unsharp image signals obtained from the reference original image signal S_{org} and those obtained from an object low resolution image signal,

Figure 54 is a view showing correspondence between the band-limited signals obtained from the reference original image signal S_{org} and those obtained from an object low resolution image signal,

Figure 55 is a view showing correspondence between the transformation functions for the band-limited signals obtained from the reference original image signal S_{org} and those for the band-limited signals obtained from an object low resolution image signal,

Figure 56 is a block diagram showing a unsharp image signal making means in the image processing system in accordance with a seventh embodiment of the present invention,

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Figure 57 is a view showing correspondence between the band-limited signals obtained from the reference original image signal S_{org} and those obtained from object original image signals,

Figure 58 is a view showing correspondence between the transformation functions for the band-limited signals obtained from the reference original image signal S_{org} and those for the band-limited signals obtained from object original image signals,

Figure 59 is a schematic block diagram showing the arrangement of an image processing system in accordance with a seventh embodiment of the present invention,

Figure 60 is a view showing the frequency response characteristic of the picture element density transformation filter,

Figure 61 is a view showing the frequency response characteristic of the interpolation filter,

Figure 62 is a view showing the frequency response characteristic of the processed image signal S_{proc} obtained by carrying out the frequency enhancement processing by use of the transformation functions f_k set for the frequency enhancement processing of the base original image signal S_{org}' on the 5-line transformed original image signal $S_{org}5$ and by doubling the obtained intermediate processed image signal S_{proc}' by use of the interpolation filter whose filtering characteristic is F2,

Figure 63 is a view showing the frequency response characteristics of the band-limited signals obtained from the

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base original image signal S_{org}',

Figure 64 is a flow chart showing operation of the image processing system in accordance the seventh embodiment of the present invention,

5   Figure 65 is a schematic block diagram showing the arrangement of an image processing system in accordance with an eighth embodiment of the present invention,

Figures 66A to 66C are views for illustrating encoding the hierarchical image signals,

10   Figure 67 is a view showing frequency response characteristics of the low resolution image signals which are restored up to a resolution equal to 1/2 of that of the base original image signal S_{org}' and up to a resolution equal to 1/4 of that of the base original image signal S_{org}' when the base

15   original image signal S_{org}' has been decomposed by use of wavelet transformation functions having first coefficients of filter,

Figure 68 shows the same when the base original image signal S_{org}' has been decomposed by use of wavelet transformation functions having second coefficients of filter,

20   Figure 69 is a view showing an example of table data storing therein a space frequency characteristic representing the characteristic of enlargement or the characteristic of contraction, and

Figures 70A and 70B are views showing the parameters

25   employed in a Gaussian function representing the space frequency characteristic which in turn represents the characteristic of

enlargement or the characteristic of contraction.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An image processing system in accordance with a first embodiment of the present invention will be described, hereinbelow. The image processing system is for carrying out a frequency enhancement processing by use of unsharp image signals on an original image signal obtained by reading out a radiation image of a human body recorded on a stimulable phosphor sheet so that an image suitable for diagnosis can be obtained. An image reproduced on the basis of the processed image signal is mainly recorded on photographic film and used in diagnosis.

In Figure 1, an image processing system 1 in accordance with a first embodiment of the present invention comprises an unsharp image signal making means 2 which makes a plurality of unsharp image signals from an original image signal S_{org} which is input from an image read-out apparatus or the like and has a predetermined picture element density, and a non-linear processing means 3 which carries out a frequency enhancement processing for enhancing a particular frequency and obtains a processed image signal S_{proc}. The image processing system 1 further comprises a transformation function defining means 4 and a picture element density information input means 5. The transformation function defining means 4 is a means which defines transformation functions which the non-linear processing means 3 uses in the transformation processing, for instance, by determining parameters such as inclinations of the functions

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and degrees of non-linearity on the basis of picture element density information M input from the picture element density information input means 5 and defining the functions on the basis of the parameters. The picture element density information input means 5 is a means for obtaining picture element density information M on the original image signal S_{org}. The picture element density information M may be input as a value by the operator by a keyboard or by the operator selecting a value from a plurality of picture element densities displayed on a control screen. Further, the picture element density information M may be attached to the original image signal S_{org} in the read-out apparatus and may be detected by the image processing system 1. The picture element density information M may be input in any way so long as the transformation function defining means 4 can recognize the picture element density of the original image signal S_{org}.

Making the unsharp image signals will be first described, hereinbelow. As shown in Figure 2, the unsharp image signal making means 2 comprises first to n-th filtering means 10. The first filtering means 10 carries out a filtering processing on the original image signal S_{org} in x- and y-directions and makes a low resolution image signal B1 which is lower than the original image signal S_{org} in resolution. The second filtering means 10 carries out a similar filtering processing on the low resolution image signal B1 thus obtained and makes a low resolution image signal B2 which is lower than the low resolution image signal

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B1 in resolution, and the third filtering means 10 carries out a similar filtering processing on the low resolution image signal B2 thus obtained and makes a low resolution image signal B3 which is lower than the low resolution image signal B3 in resolution. In this manner, the n-th filtering means 10 carries out a similar filtering processing on the low resolution image signal Bn-1 and makes a low resolution image signal Bn which is lower than the low resolution image signal Bn-1 in resolution. The unsharp image signal making means 2 further comprises first to n-th interpolation means 11. The interpolation means 11 carry out an interpolation/enlargement processing on the low resolution image signals B1 to Bn obtained at the respective stages of filtering, and makes a plurality of unsharp image signals $S_{us}1$ to $S_{us}N$ which are different in sharpness.

In this particular embodiment, filters which substantially conform to one-dimensional Gaussian distribution are used in the filtering processing. That is, coefficients of the filters are determined according the following formula (4) which relates to a Gaussian signal.

$$f(t) = e^{-\frac{t^2}{2\sigma^2}}$$ (4)

This is because the Gaussian signal is good in localization in both a real space and a frequency space. For example, the 7×1 one-dimensional filters are as shown in Figure 3A when $\sigma=1$ in formula (4).

The filtering is carried out on the original image signal

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S_{org} or the low resolution image signals every second picture element as shown in Figure 4. When such filtering is carried out in both x- and y- directions, the number of picture elements in obtained low resolution image signal is reduced to 1/4 of the preceding image signal (e.g., the original image signal S_{org} in the case of the low resolution image signal B1, and the low resolution image signal B1 in the case of the low resolution image signal B2). That is, the number of picture elements in each of the low resolution image signals B_k(k stands for 1 to n) is $1/2^{2k}$ of the original image signal S_{org}.

The interpolation/enlargement processing to be carried out on the low resolution image signals Bk thus obtained will be described, hereinbelow. Though various methods of interpolation such as B-spline can be employed, a Gaussian signal is also employed in the interpolation in this particular embodiment since low-pass filters based on Gaussian signals are employed in the filtering processing. Specifically, an approximation, $\sigma=2^{k-1}$, is employed in the following formula (5).

$$I(t) = 2 \cdot \sigma \cdot e^{-\frac{t^2}{2\sigma^2}} \qquad (5)$$

When interpolating the low resolution image signal B1, $\sigma=1$ since k=1. In this case, a one-dimensional filter of 5×1 such as shown in Figure 5 is employed in the interpolation. In this interpolation, a picture element of 0 in value is interpolated every second picture element in the low resolution image signal B1, whereby the low resolution image signal B1 is

enlarged to a size equal to the size of the original image, and the interpolated low resolution image signal B1 is subjected to a filtering processing using the one-dimensional filter shown in Figure 5.

5   This interpolation/enlargement processing is carried out on all the low resolution image signals B1 to Bn. When interpolating a low resolution image signal Bk, a filter which is $3\times2^k-1$ in length is prepared according to formula (5) and 2^k-1 picture elements of 0 in value are interpolated between each

10   pair of adjacent picture elements, whereby the low resolution image signal Bk is enlarged to a size equal to the size of the original image signal. Then the interpolated low resolution image signal Bk is subjected to a filtering processing using the filter which is $3\times2^k-1$ in length.

15   The frequency enhancement processing has been generally based on the assumption that the picture element density at which the original image signal S_{org} is obtained is constant, and the processed image signal S_{proc} has been made without taking into account the picture element density. However, in a practical

20   image processing system, various image signals are input and all the image signals are not the same in picture element density. For example, in the radiation image processing system of this embodiment, the picture element density differs according to the size of the stimulable phosphor sheet, and is 5 lines/mm

25   in a half size, 6.7 lines/mm in a quarter size and 10 lines/mm in a sixmo size. Further, the user can freely set the picture

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element density.

When image signals which are different in picture element density and accordingly in Nyquist frequency are subjected to a filtering processing using the same low-pass filters and to the same interpolation processing, band-limited signals obtained from unsharp signals $S_{us}k$ in a manner to be described later become different from each other in frequency response characteristic according to the picture element density. For example, when band-limited signals are made from unsharp image signals $S_{us}k$ obtained by carrying out a filtering processing using a one-dimensional filter shown in Figure 3A on original image signals which are respectively read at 10 lines/mm, 5 lines/mm and 6.7 lines/mm, the band-limited signals from the original image signal at 6.7 lines/mm quite differs in frequency bands from those from the original image signals at 10 lines/mm and 5 lines/mm though the latter band-limited signals are the same in frequency bands since the original image signal 5 lines/mm is a half of that at 10 lines/mm in Nyquist frequency. In this embodiment, the filtering processing is carried out using the filter shown in Figure 3A on original image signals at 10 lines/mm and 5 lines/mm and using the filter shown in Figure 3B on original image signals at 6.7 lines/mm so that the frequency bands of the obtained band-limited signals become substantially the same irrespective of the picture element density of the original image signal. The unsharp image signal making means 2 switches the filters on the basis of the picture element density

information M input from the picture element density information input means 5.

The non-linear processing to be carried out on the unsharp image signals $S_{us}k$ (k stands for 1 to n) thus obtained will be described, hereinbelow. Figure 6 shows a system for carrying out a frequency enhancement processing (an example of the non-linear processing) together with the unsharp image signal making means 2. As shown in Figure 6, unsharp image signals $S_{us}k$ are made from the original image signal S_{org} and differences between the original image signal S_{org} and the unsharp image signals $S_{us}k$ are taken by respective subtractors 21, whereby band-limited signals ($S_{org}-S_{us}1$, $S_{us}1-S_{us}2$, and the like) which are components in limited frequency bands of the original image signal S_{org} are made.

The band-limited signals are transformed to predetermined amplitudes with different transformation functions f_1 to f_N in respective transformation circuits 22 and the transformed band-limited signals are added up and further added to the original image signal S_{org} by an operator 23 according to the following formulae (2), whereby a processed image signal S_{proc} in which a desired frequency components is enhanced to a required degree is generated.

$$S_{proc}=S_{org}+\beta(S_{org}) \times F_{usm}(S_{org}, \ S_{us}1, \ S_{us}2, \ \cdots\cdots \ S_{us}N)$$

$$F_{usm}(S_{org}, \ S_{us}1, \ S_{us}2, \ \cdots\cdots \ S_{us}N)$$

$$=f_1(S_{org}-S_{us}1)+f_2(S_{us}1-S_{us}2)+ \ \cdots$$

$$+ \ f_k(S_{us}k-1-S_{us}k)+ \ \cdots \ +f_N(S_{us}N-1-S_{us}N) \qquad (2)$$

wherein S_{proc} is a processed image signal in which the high-frequency components are enhanced, S_{org} is an original image signal, $S_{us}k$ (k=1 to N) are unsharp image signals, f_k(k=1 to N) is a transformation function, and $\beta(S_{org})$ is a coefficient of enhancement determined on the basis of the original image signal.

As the transformation functions f_k, non-linear functions represented by the following formula (6) are employed.

$$f(S_{in})=S_{out}=S_{in}\times Y\times\{exp(X/S_{in})-1\}/\{exp(X/S_{in})+1\} \qquad (6)$$

wherein S_{in} represents an input signal, S_{out} represents an output signal, X represents a parameter which governs the degree of non-linearity, and Y represents a parameter which controls the inclination of the overall function. By adjusting the parameters X and Y, the frequency response characteristic of the band-limited signal can be changed.

The processed image signal S_{proc} is thus made. The problem to be solved by this embodiment and the manner of solving the problem in this embodiment will be described through an example, hereinbelow. When the filtering processing is carried out on the original image signal S_{org} using a filter which is determined according to the picture element density of the original image signal S_{org}, thereby obtaining unsharp image signals $S_{us}k$, and band-limited signals are obtained from the unsharp image signals $S_{us}k$ as disclosed in Japanese Unexamined Patent Publication No. 10(1998)-63837, the band-limited signals can be in the same frequency bands irrespective of the picture element density of the original image signal S_{org}. However, in this case, the

frequency response characteristics of the band-limited signals differ according to the picture element density of the original image signal S_{org}.

Figure 7 shows the frequency response characteristics of band-limited signals ($S_{org}-S_{us}1$, $S_{us}1-S_{us}2$, $S_{us}2-S_{us}3$, $S_{us}3-S_{us}4$, $S_{us}4-S_{us}5$, $S_{us}5-S_{us}6$) obtained by carrying out, on an original image signal at a picture element density of 10 lines/mm, the filtering processing using the one-dimensional filter shown in Figure 3A. Figure 8 shows the frequency response characteristics of band-limited signals ($S_{org}-S_{us}1$, $S_{us}1-S_{us}2$, $S_{us}2-S_{us}3$, $S_{us}3-S_{us}4$, $S_{us}4-S_{us}5$, $S_{us}5-S_{us}6$) obtained by carrying out, on an original image signal at a picture element density of 6.7 lines/mm, the filtering processing using the one-dimensional filter shown in Figure 3B. Figure 9 shows the frequency response characteristics of band-limited signals ($S_{org}-S_{us}1$, $S_{us}1-S_{us}2$, $S_{us}2-S_{us}3$, $S_{us}3-S_{us}4$, $S_{us}4-S_{us}5$, $S_{us}5-S_{us}6$) obtained by carrying out, on an original image signal at a picture element density of 5 lines/mm, the filtering processing using the one-dimensional filter shown in Figure 3A. As can be seen from Figures 7 to 9, though the maximum frequency band of the band-limited signals can be determined according to the picture element density, the peak frequencies of the band-limited signals obtained from the respective original image signals other than the maximum frequency band are reduced 1/2 by 1/2, e.g., 1 (only in the case of picture element density of 10 lines/mm), 0.5, 0.25, 0.125 ···. That is, the peak frequency of k-th band-limited signal is

1/2 of (k-1)-th band-limited signal for each picture element density. Whereas, the response at each peak frequency, that is, energy of each band-limited signal, differs according to the picture element density. Accordingly, if the same parameters X and Y (formula (6)) are used for different picture element densities, the frequency response characteristic of the obtained processed image signal S_{proc} differs according to the picture element density of the original image signal S_{org}.

In accordance with the present invention, in order to overcome this problem, the transformation function defining means 4 sets the parameters X and Y of the transformation function on the basis of the picture element density information M input from the picture element density information input means 5 and the band-limited signals are transformed according to the transformation function which is defined according to the picture element density of the original image signal S_{org}. Figure 10 shows in detail the structure of the transformation function defining means 4. As shown in Figure 10, the transformation function defining means 4 comprises a parameter setting means 7 and a memory 8 in which combinations of parameters X and Y for each picture element density are stored.

An example of combination of parameters X and Y is shown in the following table 1. In the combinations of parameters X and Y shown in table 1, the parameters X and Y for the picture element densities of 6.7 lines/mm and 5 lines/mm are set so that a processed image signal S_{proc} having a frequency response

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substantially equal to that obtained by the parameters X and Y for the picture element density of 10 lines/mm can be obtained. In table 1, the parameters X and Y for each picture element density on higher lines are for band-limited signals in higher frequency bands, and since no band-limited signal having a frequency peak at 0.03 cycles/mm exists for the picture element densities of 6.7 lines/mm and 5 lines/mm, no parameter is given.

Table 1

10 lines/mm		6.7 lines/mm		5 lines/mm	
X	Y	X	Y	X	Y
15	1.00	20	1.00	20	1.00
20	0.99	30	0.83	30	0.81
30	0.80	40	0.67	40	0.66
40	0.66	50	0.43	50	0.42
50	0.41	60	0.32	60	0.29
60	0.29				

The parameter setting means 7 selects the combinations of parameters X and Y stored in the memory 8 according to the picture element density represented by the picture element density information M input from the picture element density information input means 5, and the selected combinations of parameters X and Y are input into the transformation function defining means 4. The transformation function defining means 4 defines the transformation functions on the basis of the selected combinations of parameters X and Y, and the non-linear processing means 3 carries out on the band-limited signals according to formulae (2) on the basis of the transformation functions thus defined.

Figure 11 shows the frequency response characteristic of the processed image signal S_{proc} obtained by processing the band-limited signals obtained from an original image signal at 10 lines/mm using the transformation functions defined in the manner described above. Figure 12 shows the frequency response characteristic of the processed image signal S_{proc} obtained by processing the band-limited signals obtained from an original image signal at 6.7 lines/mm using the transformation functions defined in the manner described above. Figure 13 shows the frequency response characteristic of the processed image signal S_{proc} obtained by processing the band-limited signals obtained from an original image signal at 5 lines/mm using the transformation functions defined in the manner described above. As can be seen from Figures 11 to 13, when the frequency enhancement processing is carried out by use of transformation functions defined by the parameters X and Y shown in table 1, the frequency response characteristic of the obtained processed image signal S_{proc} is substantially constant irrespective of the picture element density of the original image signal.

The parameters X and Y may be set, for instance, by the method disclosed in Japanese Unexamined Patent Publication No. 10(1998)-63838. This method will be described, hereinbelow. As a system for setting the parameters X and Y, a system which prompts the user to enter a desired frequency response characteristic by way of a display and recognizes through the input the frequency response characteristic which the user

desires. Specifically, the system comprises software, an input
system, a display and the like.

When setting the parameters X and Y, a screen 7a (Figure
14) which shows the frequency response characteristic curve of
the processed image signal S_{proc} obtained when the band-limited
signals are processed by the current transformation functions
(initial transformation functions). On the characteristic
curve, six movable points are displayed. That is, in the case
where the image processing is a non-linear processing using n
band-limited signals, the number of the movable points is n.

The user moves necessary point(s) to a position
corresponding to a desired frequency response characteristic
by operating a pointing device such as a mouse. Screen 7b in
Figure 14 shows this procedure. This is done so that the
responses in the respective frequency bands become equal to each
other. After the necessary points are moved, the new points are
recognized as to indicate desired frequency responses at the
frequencies designated by the points, and the frequency response
characteristic curve is recalculated and a new characteristic
curve which passes through the new points is displayed. Screen
7c in Figure 14 shows this state. When the new characteristic
curve is a desired one, the user selects the "OK" button shown
in screen 7d and otherwise selects the "Cancel" button to redo
setting parameters. The parameters may be set in other various
ways. For example, the parameter setting means may be arranged
so that a plurality of values of frequency are shown on the screen

in sequence and the user inputs a desired frequency response

characteristic for the shown frequency.

When instruction that the parameters are to be set is made,

the input desired frequency response characteristics a1 to a6

(in the case where the image processing to be carried out using

six band-limited signals) are substituted, for instance, in the

following simultaneous equations (7).

$$a1 = Y1 \times S11 + Y2 \times S21 + Y3 \times S31 + Y4 \times S41 + Y5 \times S51 + Y6 \times S61$$

$$a2 = Y1 \times S12 + Y2 \times S22 + Y3 \times S32 + Y4 \times S42 + Y5 \times S52 + Y6 \times S62$$

$$a3 = Y1 \times S13 + Y2 \times S23 + Y3 \times S33 + Y4 \times S43 + Y5 \times S53 + Y6 \times S63$$

$$a4 = Y1 \times S14 + Y2 \times S24 + Y3 \times S34 + Y4 \times S44 + Y5 \times S54 + Y6 \times S64$$

$$a5 = Y1 \times S15 + Y2 \times S25 + Y3 \times S35 + Y4 \times S45 + Y5 \times S55 + Y6 \times S65$$

$$a6 = Y1 \times S16 + Y2 \times S26 + Y3 \times S36 + Y4 \times S46 + Y5 \times S56 + Y6 \times S66$$

$$Y1{\sim}Y6 \geq 0 \qquad\qquad\qquad (7)$$

wherein a1 to a6 represent the desired frequency response

characteristics, S11 to S66 represent the frequency response

characteristics of the band-limited signals made on the basis

of the original image signal, and Y1 to Y6 represent parameters

representing the inclinations of the transformation functions

near 0. The degree of the equations is determined according to

the number of the band-limited signals and the above equations

are given only as an example.

By solving the simultaneous equations (7) with the desired

frequency response characteristics a1 to a5 and the frequency

response characteristics of the band-limited signals S11 to S66

taken as known values and the parameters Y1 to Y6 taken as

variables, the parameters Y1 to Y6 are obtained, and the transformation functions are defined on the basis of the parameters. The parameters X representing the degree of non-linearity may be set to any values corresponding to the parameters Y1 to Y6 and, for instance, may be set to fixed values which are determined according to the picture element densities as shown in the aforesaid table 1. The parameters X and Y determined picture element density by picture element density are stored in the memory 8.

The values of the frequency response characteristics of the band-limited signals S11 to S66 are for six band-limited signals and S11 to S16 (S21 to S26, ··· S61 to S66) represent the frequency response characteristics at six frequencies of one band-limited signal. The values of the frequency response characteristics of the band-limited signals S11 to S66 can be obtained by a method of transformation normally used in frequency analysis on the basis of the coefficients of filter and the coefficients of interpolation used in making the unsharp image signals.

The parameters X and Y may be set by trial and error.

Operation of the image processing system 1 of this embodiment will be described with reference to the flow chart shown in Figure 15. An original image signal S_{org} is first input into the image processing system 1, for instance, from an image read-out apparatus. (step S1) The original image signal S_{org} is input into the unsharp image signal making means 2 and unsharp

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image signals $S_{us}k$ are made according to the picture element

density of the original image signal S_{org}. (step S2) Picture

element density information M on the original image signal S_{org}

is input into the picture element density information input means

5. (step S3) Then the combinations of the parameters are

selected in the transformation function defining means 4 on the

basis of the picture element density information M in the manner

described above, and the transformation functions are defined

on the basis of the selected combinations of the parameters.

(step S4) Steps S3 and S4 may be executed before steps S1 and

S2. When steps S3 and S4 and steps S1 and S2 are executed in

parallel, the operation time can be shortened. Frequency-

limited signals are made on the basis of the unsharp image signals

$S_{us}k$ and the non-linear processing (frequency enhancement

processing) represented by the aforesaid formulae (2) is

executed by the non-linear processing means 3 on the basis of

the transformation functions defined by the transformation

function defining means 4, whereby a processed image signal S_{proc}

is obtained. (step S5)

The frequency enhancement processing is for making add

signals, which are to be added to the original image signal in

order to enhance desired frequency components, by use of the

unsharp image signals. The frequency bands are differently

processed so that the signals in the respective frequency bands

forming the respective add signals become desired signals in

order to prevent generation of artifact due to the frequency

enhancement processing. In order to make the desired signals, it is preferred that signals have desired frequency response characteristics irrespective of the picture element density of the original image signal S_{org}. In the image processing system 1 of this embodiment, the parameters of the transformation functions are defined so that the frequency response characteristic of the processed image signal S_{proc} become substantially constant irrespective of the picture element density of the original image signal S_{org}, and accordingly, a processed image signal S_{proc} having substantially constant frequency response characteristic can be obtained irrespective of the picture element density of the original image signal S_{org}.

Though, in the embodiment described above, the frequency enhancement processing represented by the aforesaid formulae (2) is carried out as a non-linear processing, a dynamic range compression processing and a frequency enhancement processing may be executed simultaneously as a non-linear processing. Figure 16 is a view showing a system for executing a frequency enhancement processing and a dynamic range compression processing as a non-linear processing in an image processing system in accordance with a second embodiment of the present invention. As shown in Figure 16, differences between two of the original image signal S_{org} and the unsharp image signals $S_{us}k$ made by the filtering means 10 and the interpolation means 11 are taken, whereby a plurality of band-limited signals (e.g., $S_{org}-S_{us}1$, $S_{us}1-S_{us}2$ and the like) respectively representing

frequency components in limited frequency bands of the original

image signal are made. The filters used in the filtering means

19 are determined according to the picture element density of

the original image signal in the manner similar to that described

5   above. The band-limited signals thus obtained are input into

first and second transformation sections 3a and 3b and processed

by respective transformation means 22a and 22b in the first and

second transformation sections 3a and 3b.

Transformation by the transformation means 22a in the

10   first transformation section 3a is executed by use of the

transformation functions defined on the basis of the picture

element density information M on the original image signal S_{org}

as described above. For example, the transformation functions

shown in Figure 17 or 18 or combinations of the transformation

15   functions shown in Figures 17 and 18 are used. These

transformation functions are obtained by setting the parameters

so that the frequency response characteristic of the processed

image signal S_{proc} becomes substantially constant irrespective

of the picture element density of the original image signal S_{org}.

20   In accordance with the transformation functions shown in

Figure 17, the band-limited signals are transformed so that those

which are large in amplitude are suppressed and the degree of

suppression is increased as the frequency band of the band-

limited signal becomes higher. This is for taking into account

25   the fact that higher frequency components contained in edges

of an actual radiation image is smaller in amplitude than low

frequency components.   In actual radiation images, even a substantially sharp edge is not in the form of a correct step and the amplitude often becomes smaller as the frequency becomes higher.   Accordingly, it is preferred that suppression be made from a smaller amplitude as the frequency of the band-limited signals becomes higher.   The functions shown in Figure 17 serve for this purpose.

The transformation functions shown in Figure 18 are for transforming the band-limited signals to those having values not larger than absolute values of the band-limited signals, which values are determined on the basis of the absolute values of the band-limited signals.   As the frequency of the frequency band to be processed by the function becomes lower, the absolute value of a transformed image signal obtained by transforming a band-limited signal whose absolute value is in a predetermined range near 0 becomes smaller.   That is, the functions all pass through the origin and all have inclinations smaller than 1. Further, the inclination near 0 is smaller as the frequency of the frequency band to be processed by the function becomes lower. When an add signal obtained by adding up the transformed image signals is added to the original image signal S_{org}, these functions contribute to smoothen the joint between the original image signal S_{org} and the add signal, that is, rise of the signal.

Similarly transformation by each transformation means 22b in the second transformation section 3b is executed by use of the transformation functions shown in Figure 19 or 18 or

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combinations of the transformation functions shown in Figures 19 and 18. The transformed image signals output from the first and second transformation sections 3a and 3b are respectively input into operators 23a and 23b. The operator 23a executes

5   operation for making signals necessary for the frequency enhancement processing, and the operator 23b executes operation for making signals necessary for the dynamic range compression processing.

The operator 23a executes a frequency enhancement

10   processing similar to that described above with reference to Figure 6. That is, the band-limited signals transformed by the first transformation section 3a are added up, and an add signal thus obtained is multiplied by a coefficient of enhancement β which is determined according to the value of the original image

15   signal S_{org}.

The operator 23b executes a dynamic range compression processing in the following manner. The band-limited signals transformed by the second transformation section 3b are added up, and an add signal thus obtained is subtracted from the

20   original image signal S_{org}. Then the differential signal thus obtained is transformed on the basis of a transformation function, thereby obtaining a coefficient of dynamic range compression. The signals respectively obtained by the operators 23a and 23b are added to the original image signal S_{org} by an adder 28, whereby

25   a processed image signal S_{proc} is obtained.

The processing described above is represented by the

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following formula (3).

$$S_{proc} = S_{org} + \beta(S_{org}) \times F_{usm}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)$$
$$+ D\{S_{org} - F_{drc}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)\} \quad (3)$$

$$F_{usm}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)$$

$$= \{f_{u1}(S_{org}-S_{us}1)+f_{u2}(S_{us}1-S_{us}2)+ \cdots$$

$$+ f_{uk}(S_{us}k-1-S_{us}k)+ \cdots +f_{uN}(S_{us}N-1-S_{us}N)$$

$$F_{drc}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)$$

$$= \{f_{d1}(S_{org}-S_{us}1)+f_{d2}(S_{us}1-S_{us}2)+ \cdots$$

$$+ f_{dk}(S_{us}k-1-S_{us}k)+ \cdots +f_{dN}(S_{us}N-1-S_{us}N)$$

wherein S_{proc} is a processed image signal, S_{org} is an original image signal, $S_{us}k$ (k=1 to N) is an unsharp image signal, f_{uk}(k=1 to N) is a transformation function used in the first transformation section, f_{dk}(k=1 to N) is a transformation function used in the second transformation section, $\beta(S_{org})$ is a coefficient of enhancement determined on the basis of the original image signal, and $D\{S_{org}-F_{drc}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)\}$ is a coefficient of dynamic range compression determined on the basis of the low frequency component signal, D being a function for transforming $D\{S_{org}-F_{drc}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)\}$.

In the image processing system shown in Figure 16, the add signal used in the frequency enhancement processing and that used in the dynamic range compression processing are separately obtained on the basis of the original image signal S_{org} and are finally added. However, it is possible to first carry out on one of the frequency enhancement processing and the dynamic range compression processing on the original image signal S_{org} and to

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carry out the other processing on the resultant signal. Generally the lower density portion of a radiation image includes a relatively large amount of noise since the lower density portion is exposed to less radiation upon taking the radiation image. Since the frequency enhancement processing is a density-dependent processing where the degree of enhancement is increased with increase in density, the low density portion is not enhanced and accordingly noise is not enhanced when the frequency enhancement processing is directly carried out on the original image signal. To the contrast, when the frequency enhancement processing is carried out after the dynamic range compression processing is carried out on the original image signal, the low density portion is increased in its density by the dynamic range compression processing, and accordingly, the low density portion is enhanced by the following frequency enhancement processing, whereby noise is also enhanced. Accordingly, it is preferred that each signal be made on the basis of the original image signal S_{org}. Further also from the viewpoint of saving the processing time, it is preferred that the two processings be executed in parallel.

By defining the parameters for the transformation functions so that the frequency response characteristic of the processed image signal S_{proc} becomes constant irrespective of the picture element density of the original image signal S_{org}, the processed image signal S_{proc} can have a substantially constant frequency response characteristic irrespective of the picture

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element density of the original image signal S_{org}.

In the second embodiment described above, when the parameters of the transformation functions are set as shown in the following table 2 in the case where the picture element density of the original image signal is 10 lines/mm, the frequency response characteristic of the processed image signal S_{proc} becomes as shown in Figure 20. As shown in Figures 7 to 9, in the case of an original image signal at 10 lines/mm, there exists a band-limited signal corresponding to 1 cycle/mm, but in the case of an original image signal at 6.7 lines/mm or at 5 lines/mm, there exists no band-limited signal corresponding to 1 cycle/mm. Accordingly, in the case of original image signals at 6.7 lines/mm and at 5 lines/mm, the frequency response characteristics of the processed image signals S_{proc} cannot conform to the processed image signal S_{proc} for the original image signal at 10 lines/mm over the entire frequency bands. In an image obtained by reproducing a processed image signal, the low frequency components are visually more prominent than the high frequency components. Accordingly, in such a case, it is preferred that the transformation functions for band-limited signals at 6.7 lines/mm and at 5 lines/mm be defined by the parameters X and Y shown in table 2 so that the high frequency components not lower than 1 cycle/mm conform to those of the band-limited signals at 10 lines/mm to a certain extent and the low frequency components lower than 1 cycle/mm conform to those of the band-limited signals at 10 lines/mm. When the parameters

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of the transformation functions are set as shown in the following table 2 in the case where the picture element densities of the original image signals are 6.7 lines/mm and 5 lines/mm, the frequency response characteristics of the processed image signals S_{proc} become as shown in Figures 21 and 22. As shown in Figures 21 and 22, when original image signals at 6.7 lines/mm and 5 lines/mm are processed by use of transformation functions defined by the parameters shown in table 2, the frequency response characteristics of the processed image signals S_{proc} well conform to the processed image signal S_{proc} for the original image signal at 10 lines/mm as for the low frequency components lower than 1 cycle/mm though less conform to the processed image signal S_{proc} for the original image signal at 10 lines/mm as for the high frequency components not lower than 1 cycle/mm. Accordingly, a processed image signal S_{proc} the frequency response characteristic of which is substantially constant irrespective of the picture element density of the original image signal at least for the low frequency components, which are visually more prominent than the high frequency components, can be obtained.

Table 2

10 lines/mm		6.7 lines/mm		5 lines/mm	
X	Y	X	Y	X	Y
15	1.00	20	0.93	20	0.92
20	0.83	30	0.44	30	0.42
30	0.42	40	0.37	40	0.36
40	0.36	50	0.18	50	0.17
50	0.17	60	0.13	60	0.12
60	0.12				

Though, in the embodiments described above, the original

image signal S_{org} is an image signal read out from a stimulable phosphor sheet, the original image signal S_{org} may be any image signal provided that the resolution of the image represented by the image signal, e.g., the relation between the size of the object and the sampling intervals (dpi), is known.

Further, though in the embodiments described above, non-linear functions are used and a non-linear processing is carried out on the band-limited signals, linear functions or constants may be employed as the transformation functions. In such a case, the parameters of the linear functions or the values of the constants are set according to the picture element density of the original image signal.

Further, though, in the embodiments described above, the unsharp image signals are obtained from the original image signal by filtering and interpolation/enlargement and the band-limited signals are obtained from the original image signal and the unsharp image signals, the band-limited signals may be made, for instance, by transforming the original image signal to multiple resolution image signals by a wavelet transformation or a Laplacian pyramid, making the unsharp image signals from the image signals at the respective resolutions and making the band-limited signals from the unsharp image signals.

Further, though, in the embodiments described above, the parameter setting means 7 shown in Figure 10 is arranged to set the parameters X and Y on the basis of the original image signal and the picture element density thereof each time an original

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image signal S_{org} is input, the parameter setting means 7 may be arranged to determine the parameters X and Y for the original image signal S_{org} by comparing the picture element density of the original image signal S_{org} with reference picture element densities which have been stored in the memory 8 together with the parameters X and Y for the respective picture element densities and by setting, as the parameters X and Y for the original image signal S_{org}, the parameters X and y for the reference picture element density closest to the picture element density of the original image signal S_{org}. The reference picture element density closest to the picture element density of the original image signal S_{org} may be determined, for instance, in the following manner. That is, assuming that three reference picture element densities stored in the memory 8 together with the parameters X and Y for the respective reference picture element densities are a, b and c (a<b<c) and the picture element density of the original image signal S_{org} to be processed is x, the reference picture element density is c when x>b+(c-b)/2, is b when b+(c-b)/2≥x>a+(b-a)/2, and is a when a+(b-a)/2≥x. Specifically the reference picture element densities may be at least two of 10 lines/mm, 6.7 lines/mm and 5 lines/mm. In this case, when the picture element density of the original image signal S_{org} to be processed is higher than 6.7+(10-6.7)/2=8.35, the combinations of the parameters X and Y for the picture element density of 10 lines/mm shown in table 1 or table 2 are set as the parameters X and Y for the original image signal S_{org}. When

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the picture element density of the original image signal S_{org} to be processed is not higher than 6.7+(10-6.7)/2=8.35 and higher than 5+(6.7-5)/2=5.85, the combinations of the parameters X and Y for the picture element density of 6.7 lines/mm shown in table 1 or table 2 are set as the parameters X and Y for the original image signal S_{org}. When the picture element density of the original image signal S_{org} to be processed is not higher than 5+(6.7-5)/2=5.85, the combinations of the parameters X and Y for the picture element density of 5 lines/mm shown in table 1 or table 2 are set as the parameters X and Y for the original image signal S_{org}.

It is preferred that the parameters selected be stored related to the processed image signal S_{proc} and/or the picture element density of the original image signal S_{org}. With this arrangement, when an image is output (output as a hard copy on photographic film or displayed on a CRT or the like) another time, an image at a quality equivalent to that of a previously output image can be obtained. The parameters selected and the picture element density of the original image signal S_{org} may be stored either in the same storage medium or different storage media.

An image processing system in accordance with a third embodiment of the present invention will be described, hereinbelow. An image processing system 101 in accordance with the third embodiment of the present invention is also for carrying out a frequency enhancement processing by use of unsharp

image signals on an original image signal obtained by reading out a radiation image of a human body recorded on a stimulable phosphor sheet so that an image suitable for diagnosis can be obtained. An image reproduced on the basis of the processed image signal is mainly recorded on photographic film and used in diagnosis.

As shown Figure 23, the image processing system 101 in accordance with the third embodiment of the present invention is substantially the same as the image processing system 1 in accordance with the first embodiment of the present invention. Accordingly, in Figure 23, the elements analogous to those shown in Figure 1 are given the same reference numerals and will not be described in detail here. The image processing system of this embodiment comprises an unsharp image signal making means 2, a processing means 3 which carries out a frequency enhancement processing for enhancing a particular frequency and obtains a processed image signal S_{proc}, a transformation function calculating means 104 and a resolution information input means 105. The image processing system of the third embodiment mainly differs from that of the first embodiment in arrangement of the transformation function calculating means 104. That is, in this embodiment, transformation function calculating means 104 calculates the transformation functions, which the processing means 3 uses in the frequency enhancement processing, by correcting reference transformation functions which are employed to carry out the frequency enhancement processing on

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an original image signal having a known reference picture element

density, according to the resolution of the original image signal

S_{org} represented by the resolution information M input from the

resolution information input means 105, as will become apparent

5   later. The transformation functions for the original image

signal have been determined and stored in advance.

Unsharp image signals $S_{us}k$ are made in the same manner as

described above in conjunction with Figure 2 and the frequency

enhancement processing is carried out by use of the unsharp image

10   signals $S_{us}k$ in the same manner as described above in conjunction

with Figure 6.

In this embodiment, the transformation functions f_k (k

stands for 1 to N) for transforming the band-limited signals

are determined in the following manner. In this particular

15   embodiment, the transformation functions f_k are constants and

the reference resolution is 10 lines/mm. Figure 24 shows the

frequency response characteristics of the band-limited signals

obtained from an original image signal S_{org} having a resolution

of 10 lines/mm. As shown in Figure 24, six band-limited signals

20   are obtained from the original image signal S_{org}. The original

image signal S_{org} having a resolution of 10 lines/mm is 5 cycles/mm

in Nyquist frequency. The peak frequency of the band-limited

signal in the highest frequency band falls on the Nyquist

frequency. The peak frequency of the band-limited signal in the

25   second highest frequency band is 1.0 cycle/mm, 1/5 of the Nyquist

frequency. The peak frequency of the band-limited signal is

reduced 1/2 by 1/2, e.g., 0.5 cycles/mm, 0.25 cycles/mm/ 0.12

cycles/mm and 0.06 cycles/mm, as the frequency band of the

band-limited signal becomes lower.   In this particular

embodiment, the transformation functions f_k (k stands for 1 to

5   N) for transforming the band-limited signals obtained from the

original image signal S_{org} having a resolution of 10 lines/mm are

as shown in the following table 3.

Table 3

peak frequency (cycles/mm)	5	1.0	0.5	0.25	0.12	0.06
transformation function	1.00	0.90	0.80	0.60	0.40	0.20

10   In order to enhance a desired frequency component of the

original image signal S_{org}, it is necessary to carry out the

frequency enhancement processing by use of transformation

functions f_k determined frequency by frequency of the band-

limited signals. However, when the transformation functions

15   for an original image signal S_{org} having a resolution of 10

lines/mm are used, as they are, for frequency enhancement

processing of an original image signal S_{org} having a resolution

of 300dpi, the frequency response characteristic of the

processed image signal S_{proc} differs from that of the processed

20   image signal S_{proc} obtained from the original image signal S_{org}

having a resolution of 10 lines/mm.   In Figure 25, the solid line

shows the frequency response characteristic of the processed

image signal S_{proc} obtained by carrying out the frequency

enhancement processing by use of the transformation functions

25   shown in table 3 on the original image signal S_{org} at 10 lines/mm

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and the broken line shows that of the processed image signal S_{proc} obtained by carrying out the frequency enhancement processing by use of the transformation functions shown in table 3 on the original image signal S_{org} at 300dpi.

5   In order to overcome this problem, when an original image signal S_{org} having a resolution different from 10 lines/mm (reference resolution) is input, the transformation functions shown in table 3 (reference transformation functions) are corrected according to the resolution (300dpi in this particular embodiment) of the input original image signal S_{org}.

10   Figure 26 shows the frequency response characteristic of band-limited signals obtained from an original image signal S_{org} having a resolution of 300dpi. As can be seen from Figure 26, the original image signal S_{org} at 300dpi is 5.9 cycles/mm in

15 Nyquist frequency, which falls on the peak frequency of the band-limited signal in the highest frequency band. The peak frequency of the band-limited signal in the second highest frequency band is 1.018cycle/mm, 1/5 of the Nyquist frequency. The peak frequency of the band-limited signal is reduced 1/2

20 by 1/2, e.g., 0.59 cycles/mm, 0.30 cycles/mm/ 0.15 cycles/mm and 0.07 cycles/mm, as the frequency band of the band-limited signal becomes lower. This relation substantially conforms to the relation for the original image signal S_{org} at 10 lines/mm shown in Figure 24, and holds irrespective of the resolution

25. of the original image signal S_{org} so long as the filters used in making the low-resolution image signals are not changed.

The transformation functions for transforming the band-limited signals obtained from an original image signal S_{org} at 300dpi are obtained by correcting the reference transformation functions shown in table 3 on the basis of the peak frequencies of the band-limited signals obtained from the original image signal S_{org} at 10 lines/mm (reference original image signal $S_{org}0$) and those of the band-limited signals obtained from the original image signal S_{org} at 300dpi. This correction can be made, for instance, by interpolation or extrapolation. For example, the transformation function for the band-limited signals whose peak frequency is 1.18 cycles/mm is obtained by determining the relation between the peak frequencies and the values of the transformation functions on the basis of the values of the transformation functions at 5 cycles/mm and 1 cycle/mm in table 3, and substituting the value of the peak frequency (1.18) in the following formula (6) representing the determined relation between the peak frequencies and the values of the transformation functions.

$$fx=1/40 \times C+0.875 \qquad (6),$$

wherein fx=the value of the transformation function and C represents the peak frequency. Such linear interpolation is carried out on all the peak frequencies of the band-limited signals obtained from the original image signal S_{org} at 300dpi, thereby obtaining the transformation functions for all the band-limited signals as shown in the following table 4.

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Table 4

peak frequency (cycles/mm)	5.9	1.18	0.59	0.30	0.15	0.07
transformation function	1.02	0.91	0.82	0.64	0.45	0.24

Though, in the description above, linear interpolation is used, other interpolations may be employed.

In Figure 27, the solid line shows the frequency response characteristic of the processed image signal S_{proc} obtained by carrying out the frequency enhancement processing by use of the transformation functions shown in table 3 on the original image signal S_{org} at 10 lines/mm and the broken line shows that of the processed image signal S_{proc} obtained by carrying out the frequency enhancement processing by use of the transformation functions shown in table 4 on the original image signal S_{org} at 300dpi. As can be seen from Figure 27, the processed image signals S_{proc} are substantially equal to each other in frequency response characteristic.

Operation of the image processing system 101 of this embodiment will be described with reference to the flow chart shown in Figure 28. An original image signal S_{org} is first input into the image processing system 101, for instance, from an image read-out apparatus. (step S11) The original image signal S_{org} is input into the unsharp image signal making means 2 and unsharp image signals $S_{us}k$ are made by the unsharp image signal making means 2 . (step S12) Resolution information M on the original image signal S_{org} is input into the resolution information input means 105. (step S13) Then the transformation function

calculating means 4 calculates the transformation functions on the basis of the resolution information M in the manner described above. (step S14) Steps S3 and S4 may be executed before steps S1 and S2. When steps S3 and S4 and steps S1 and S2 are executed in parallel, the operation time can be shortened. Frequency-limited signals are made on the basis of the unsharp image signals $S_{us}k$ and the frequency enhancement processing represented by the aforesaid formulae (2) is executed by the processing means 3 on the basis of the transformation functions calculated by the transformation function calculating means 4, whereby a processed image signal S_{proc} is obtained. (step S15)

The frequency enhancement processing is for making add signals, which are to be added to the original image signal in order to enhance desired frequency components, by use of the unsharp image signals. The frequency bands are differently processed so that the signals in the respective frequency bands forming the respective add signals become desired signals in order to prevent generation of artifact due to the frequency enhancement processing. In order to make the desired signals, it is preferred that signals have desired frequency response characteristics irrespective of the resolution of the original image signal S_{org}. In the image processing system 101 of this embodiment, the transformation functions are calculated so that the frequency response characteristics of the processed image signal S_{proc} become substantially constant irrespective of the resolution of the original image signal S_{org}, and accordingly,

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a processed image signal S_{proc} having substantially constant frequency response characteristics can be obtained irrespective of the resolution of the original image signal S_{org}.

Further, since the transformation functions for original image signals S_{org} having resolutions different from the reference resolution are obtained by correcting the reference transformation functions, it is not necessary to prepare a plurality of transformation functions for various resolutions, whereby trouble to manage a plurality of transformation functions can be saved.

Though, in the third embodiment described above, only one series of reference transformation functions for one reference resolution, 10 lines/mm, are prepared and transformation functions for other resolution are calculated on the basis of the one series of reference transformation functions, it is possible to prepare a plurality of series of reference transformation functions for a plurality of resolutions which are relatively frequently used and to calculate transformation functions for an object picture element density on the basis of one of the reference resolutions. For example, when first and second reference transformation functions for first and second resolutions are prepared in advance, transformation functions for an object original image signal to be processed may be calculated on the basis the first reference transformation functions when the resolution of the object original image signal is lower than the middle between the first and second resolutions

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as shown by arrow A in Figure 29A and on the basis the second reference transformation functions when the resolution of the object original image signal is not lower than the middle between the first and second resolutions as shown by arrow B. Otherwise, the transformation functions for the object original image signal may be calculated on the basis the first reference transformation functions when the resolution of the object original image signal is not higher than the first resolution as shown by arrow C in Figure 29B and on the basis the second reference transformation functions when the resolution of the object original image signal is higher than the first resolution as shown by arrow D.

Further, though in the third embodiment described above, the transformation functions are constants, the transformation functions may be non-linear functions having predetermined inclinations.

An image processing system in accordance with a fourth embodiment of the present invention, where non-linear functions are employed as the transformation functions, will be described, hereinbelow.

In the fourth embodiment, as the transformation functions f_k, non-linear functions represented by the following formula (8) are employed.

$$f(S_{in}) = S_{out} = S_{in} \times Y \times \{\exp(X/S_{in}) - 1\} / \{\exp(X/S_{in}) + 1\} \qquad (8)$$

wherein S_{in} represents an input signal, S_{out} represents an output signal, X represents a parameter which governs the degree of

non-linearity, i.e., the condition of suppression, and Y represents a parameter which controls the inclination of the overall function, i.e., the frequency response characteristic. By adjusting the parameters X and Y, the frequency response characteristic of the band-limited signal can be changed. In this embodiment, parameters X and Y shown in the following table 5 are employed. Table 5 shows combinations of parameters X and Y for the resolutions of, 10 lines/mm, 6.7 lines/mm and 5 lines/mm, and in table 5, the parameters X and Y for each resolution on higher lines are for band-limited signals in higher frequency bands. As shown in Figure 30, as the Nyquist frequency becomes lower, the number of the band-limited signals used in the non-linear processing is reduced. For example, in the case of an original image signal at 10 lines/mm, the number of the band-limited signals is 6, whereas in case of original image signals at 6.7 lines/mm and 5 lines/mm, the number of the band-limited signals is 5. This is because no band-limited signal having a frequency peak at 0.03 cycles/mm exists for the resolutions of 6.7 lines/mm and 5 lines/mm. The case where 10 lines/mm is employed as the reference resolution, the transformation functions defined by the combinations of the parameters X and Y shown in table 5 are employed as the reference transformation functions, and the resolution of the original image signal to be processed is 200dpi will be described, hereinbelow.

Table 5

10 lines/mm		6.7 lines/mm		5 lines/mm	
X	Y	X	Y	X	Y
15	1.00	20	1.00	20	1.00
20	0.99	30	0.83	30	0.81
30	0.80	40	0.67	40	0.66
40	0.66	50	0.43	50	0.42
50	0.41	60	0.32	60	0.29
60	0.29				

Figure 31 shows the frequency response characteristics of band-limited signals obtained from an original image signal S_{org} having a resolution of 200dpi. As can be seen from Figure 31, the original image signal S_{org} at 200dpi is about 4.0 cycles/mm (more strictly 3.937 cycles/mm) in Nyquist frequency, which falls on the peak frequency of the band-limited signal in the highest frequency band. The peak frequency of the band-limited signal in the second highest frequency band is 0.8 cycles/mm, 1/5 of the Nyquist frequency. The peak frequency of the band-limited signal is reduced 1/2 by 1/2, e.g., 0.4 cycles/mm, 0.2 cycles/mm/ 0.1 cycles/mm and 0.05 cycles/mm, as the frequency band of the band-limited signal becomes lower. This relation substantially conforms to the relation for the original image signal S_{org} at 10 lines/mm shown in Figure 24, and holds irrespective of the resolution of the original image signal S_{org} so long as the filters used in making the low-resolution image signals are not changed. Figure 32 shows the frequency response characteristics of the processed image signal S_{proc} obtained by processing the original image signal S_{org} at 200dpi by use of the

reference transformation functions (broken line) and the processed image signal $S_{proc}0$ obtained by processing the reference original image signal $S_{org}0$ at the reference resolution by use of the reference transformation functions (solid line). As can

5   be seen from Figure 32, the processed image signal S_{proc} is enhanced in frequency bands lower than the processed image signal $S_{proc}0$.

Accordingly, as in the third embodiment, the transformation functions for transforming the band-limited

10   signals obtained from an original image signal S_{org} at 200dpi are obtained by correcting the reference transformation functions on the basis of the resolution of the original image signal S_{org}. In this embodiment, the peak frequencies of the band-limited signals obtained from the reference original image signal S_{org}

15   at 10 lines/mm, the parameters of the reference transformation functions (the values of Y in table 5), and the peak frequencies of the band-limited signals obtained from the original image signal S_{org} at 200dpi, and the number of the transformation functions to be obtained (six) are known. Accordingly,

20   responses at peak frequencies of the band-limited signals obtained from the original image signal S_{org} at 200dpi are first obtained according to the following formulae (9) on the basis of the frequency response characteristics of the band-limited signals obtained from the reference original image signal S_{org}

25   at 10 lines/mm, the parameters Y of the reference transformation functions and the peak frequencies of the band-limited signals

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obtained from the original image signal S_{org} at 200dpi.

R1=X1[F1]*Y1+X2[F1]*Y2+X3[F1]*Y3+X4[F1]*Y4+X5[F1]*Y5+X6[F1]*Y6

R2=X1[F2]*Y1+X2[F2]*Y2+X3[F2]*Y3+X4[F2]*Y4+X5[F2]*Y5+X6[F2]*Y6

R3=X1[F3]*Y1+X2[F3]*Y2+X3[F3]*Y3+X4[F3]*Y4+X5[F3]*Y5+X6[F3]*Y6

R4=X1[F4]*Y1+X2[F4]*Y2+X3[F4]*Y3+X4[F4]*Y4+X5[F4]*Y5+X6[F4]*Y6

R5=X1[F5]*Y1+X2[F5]*Y2+X3[F5]*Y3+X4[F5]*Y4+X5[F5]*Y5+X6[F5]*Y6

R6=X1[F6]*Y1+X2[F6]*Y2+X3[F6]*Y3+X4[F6]*Y4+X5[F6]*Y5+X6[F6]*Y6

(9)

wherein R1 to R6 represent responses at peak frequencies (200dpi),
X1[F1] to X6[F6] represent responses of the band-limited signals
obtained from the reference original image signal at frequencies
of F1 to F6, Y1 to Y6 represent the parameters of the reference
transformation functions.

Then by solving the following simultaneous equations 10,
parameters A1 to A6 of the transformation functions for the
original image signal at 200dpi are obtained.

R1=Z1[F1]*A1+Z2[F1]*A2+Z3[F1]*A3+Z4[F1]*A4+Z5[F1]*A5+Z6[F1]*A6

R2=Z1[F2]*A1+Z2[F2]*A2+Z3[F2]*A3+Z4[F2]*A4+Z5[F2]*A5+Z6[F2]*A6

R3=Z1[F3]*A1+Z2[F3]*A2+Z3[F3]*A3+Z4[F3]*A4+Z5[F3]*A5+Z6[F3]*A6

R4=Z1[F4]*A1+Z2[F4]*A2+Z3[F4]*A3+Z4[F4]*A4+Z5[F4]*A5+Z6[F4]*A6

R5=Z1[F5]*A1+Z2[F5]*A2+Z3[F5]*A3+Z4[F5]*A4+Z5[F5]*A5+Z6[F5]*A6

R6=Z1[F6]*A1+Z2[F6]*A2+Z3[F6]*A3+Z4[F6]*A4+Z5[F6]*A5+Z6[F6]*A6

(10)

wherein R1 to R6 represent responses at peak frequencies (200dpi)
obtained according to formulae (9), Z1[F1] to Z6[F6] represent
responses of the band-limited signals obtained from the original

image signal at 200dpi at frequencies of F1 to F6, A1 to A6 represent the parameters of the transformation functions for the original image signal at 200dpi.

When the frequency enhancement processing is carried out on the original image signal at 200dpi by use of the transformation functions thus obtained, a processed image signal S_{proc} which is substantially constant in frequency response characteristic can be obtained irrespective of the resolution of the original image signal.

A method of calculating $Z1[F1]$ to $Z6[F6]$ in formulae (10) will be described, hereinbelow. As described above, the band-limited signals obtained from the reference original image signal $S_{org}0$ at 10 lines/mm have characteristics shown in Figure 24. The characteristic of the band-limited signal in the highest frequency band shown by the solid line can be obtained by obtaining the frequency response characteristic of the unsharp image signal by multiplying Fourier-transformed value of the coefficient of filter of the one-dimensional filter shown in Figure 3A by Fourier-transformed value of the coefficient of filter of the one-dimensional filter shown in Figure 5, and subtracting the frequency response characteristic of the unsharp image signal thus obtained from the frequency response characteristic of the reference original image signal $S_{org}0$ (=1 over the entire frequency bands). The characteristic of band-limited signals in lower frequency bands can be obtained by obtaining the frequency response characteristic of the

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unsharp image signal in the similar manner on the basis of the coefficient of filter for obtaining the low-resolution image signal corresponding to the frequency band and the coefficient of filter for obtaining the unsharp image signal, and by subtracting the frequency response characteristic of the unsharp image signal thus obtained from the frequency response characteristic of the unsharp image signal in the frequency band higher by one stage.

When the response of the band-limited signal in the highest frequency band of the reference original image signal $S_{org}0$ is represented by a function X1[Fi] (Fi being a frequency) and the values obtained by sampling the response of the band-limited signal in the highest frequency band of the reference original image signal at 2048 frequencies are represented by a function X1[I], the relation between Fi and i is as shown by the following formula (11).

$$i=2047 \times Fi/fnq \qquad (11)$$

wherein fnq represents a Nyquist frequency and $2047 \geq i \geq 0$. This is shown in Figure 33. When the function X1[i] is handled as a table, i represents addresses. By thus obtaining responses for the band-limited signals in all the frequency bands as functions X1[i] to X6[i] and handling the functions X1[i] to X6[i] as tables, values of X1[F1] to X6[F6] in the aforesaid formulae (9) and (10) can be easily obtained.

The response Z1[F1] to Z6[F6] are obtained on the basis of the functions X1[i] to X6[i]. The response Z1[Fi] at a given

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frequency Fi is obtained from the function X1[i] in the following

manner. The response Z1[Fi] is the response of the band-limited

signal in the highest frequency band in the band-limited signals

obtained from the original image signal at 200dpi. The Nyquist

frequency of the original image signal at 200dpi is 4 cycles/mm,

and when the values obtained by sampling, at 2048 frequencies,

the response of the band-limited signal at the frequency band

at which the response is Z1[Fi] are represented by a function

Z1[i], the relation between Fi and i is as shown by the aforesaid

formula (11) as in the case of X1[i]. Figure 34 shows the

relation between the functions X1[i] and Z1[i]. Though, in

concept, the functions X1[i] and Z1[i] are different functions

which are different in Nyquist frequency, the response Z1[Fi]

can be approximated by use of the function X1[i]. For example,

the response Z1[Fi] at 2 cycles/mm is obtained in the following

manner. That is, since i=2047×2/4=1024 from the aforesaid

formula (11), the response Z1[Fi] at 2 cycles/mm is given as

the value of the function X1[i] at address of 1024.

By handling the functions X1[i] to X6[i] as tables and

obtaining the address i on the basis of formula (11) and the

Nyquist frequency of the original image signal on which the

frequency enhancement processing is to be carried out, and

referring to the tables (the functions X1[i] to X6[i]) according

to the address i, the responses Z1[F1] to Z6[F6] can be

approximated.

When the frequency enhancement processing is to be carried

out on an original image signal S_{org} at 300dpi, the responses at frequencies corresponding to the peak frequencies of the band-limited signals obtained from the original image signal at 300dpi are obtained according to the aforesaid formulae (8) on the basis of the frequency response characteristics of the band-limited signals obtained from the reference original image signal, the peak frequencies of the band-limited signals obtained from the original image signal at 300dpi and the parameters Y of the reference transformation functions. Then the parameters for the transformation functions are obtained according to the aforesaid formulae (10). In the original image signal at 300dpi, the Nyquist frequency is 5.9 cycles/mm and higher than the Nyquist frequency of the reference original image signal $S_{org}0$. Since X1[F1] to X6[F6] in the aforesaid formulae (9) are functions for the range of 0 to 5 cycles/mm, no value is given for 5.9 cycles/mm by formulae (9) and R1 cannot be obtained. In this case, the peak frequencies of the band-limited signals obtained from the reference original image signal are employed as the peak frequencies of the band-limited signals obtained from the original image signal at 300dpi.

The case where the frequency enhancement processing is to be carried out on a original image signal S_{org} at 100dpi will be described, hereinbelow. Since the Nyquist frequency of the original image signal at 100dpi is about 2:0 cycles/mm (strictly 1.97 cycles/mm), the number of the band-limited signals is 5. Accordingly, the aforesaid formulae (9) and (10) are rewritten

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as the following formulae (12) and (13) and five parameters for the transformation functions are obtained according to formulae (12) and (13).

$$R1=X1[F1]*Y1+X2[F1]*Y2+X3[F1]*Y3+X4[F1]*Y4+X5[F1]*Y5+X6[F1]*Y6$$

$$R2=X1[F2]*Y1+X2[F2]*Y2+X3[F2]*Y3+X4[F2]*Y4+X5[F2]*Y5+X6[F2]*Y6$$

$$R3=X1[F3]*Y1+X2[F3]*Y2+X3[F3]*Y3+X4[F3]*Y4+X5[F3]*Y5+X6[F3]*Y6$$

$$R4=X1[F4]*Y1+X2[F4]*Y2+X3[F4]*Y3+X4[F4]*Y4+X5[F4]*Y5+X6[F4]*Y6$$

$$R5=X1[F5]*Y1+X2[F5]*Y2+X3[F5]*Y3+X4[F5]*Y4+X5[F5]*Y5+X6[F5]*Y6$$

(12)

wherein R1 to R5 represent responses at peak frequencies (100dpi), X1[F1] to X6[F5] represent responses of the band-limited signals obtained from the reference original image signal at frequencies of F1 to F5, Y1 to Y6 represent the parameters of the reference transformation functions.

$$R1=Z1[F1]*A1+Z2[F1]*A2+Z3[F1]*A3+Z4[F1]*A4+Z5[F1]*A5$$

$$R2=Z1[F2]*A1+Z2[F2]*A2+Z3[F2]*A3+Z4[F2]*A4+Z5[F2]*A5$$

$$R3=Z1[F3]*A1+Z2[F3]*A2+Z3[F3]*A3+Z4[F3]*A4+Z5[F3]*A5$$

$$R4=Z1[F4]*A1+Z2[F4]*A2+Z3[F4]*A3+Z4[F4]*A4+Z5[F4]*A5$$

$$R5=Z1[F5]*A1+Z2[F5]*A2+Z3[F5]*A3+Z4[F5]*A4+Z5[F5]*A5$$

(13)

wherein R1 to R5 represent responses at peak frequencies (100dpi) obtained according to formulae (12), Z1[F1] to Z5[F5] represent responses of the band-limited signals obtained from the original image signal at 100dpi at frequencies of F1 to F5, A1 to A5 represent the parameters of the transformation functions for the original image signal at 100dpi.

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Though, in the third and fourth embodiments described above, the frequency enhancement processing represented by the aforesaid formulae (2) is carried out as a transformation processing, a dynamic range compression processing and a

5   frequency enhancement processing may be executed simultaneously as a transformation processing. Figure 35 is a view showing a system for executing a frequency enhancement processing and a dynamic range compression processing as a transformation processing in an image processing system in accordance with a

10   fifth embodiment of the present invention. As shown in Figure 35, differences between two of the original image signal S_{org} and the unsharp image signals $S_{us}k$ made by the filtering means 110 and the interpolation means 111 are taken, whereby a plurality of band-limited signals (e.g., $S_{org}-S_{us}1$, $S_{us}1-S_{us}2$ and the like)

15   respectively representing frequency components in limited frequency bands of the original image signal are made. The band-limited signals thus obtained are input into first and second transformation sections 103a and 103b and processed by respective transformation means 122a and 122b in the first and

20   second transformation sections 103a and 103b.

Transformation by the transformation means 122a in the first transformation section 103a is executed by use of the transformation functions calculated on the basis of the resolution of the original image signal S_{org} as described above.

25   For example, the transformation functions shown in Figure 36 or 37 or combinations of the transformation functions shown in

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Figures 36 and 37 are used as the reference transformation functions and transformation functions are calculated on the basis of the reference transformation functions according to the resolution of the original image signal S_{org} to be processed so that the frequency response characteristic of the processed image signal S_{proc} becomes substantially constant irrespective of the resolution of the original image signal S_{org}.

In accordance with the transformation functions shown in Figure 36, the band-limited signals are transformed so that those which are large in amplitude are suppressed and the degree of suppression is increased as the frequency band of the band-limited signal becomes higher. This is for taking into account the fact that higher frequency components contained in edges of an actual radiation image is smaller in amplitude than low frequency components. In actual radiation images, even a substantially sharp edge is not in the form of a correct step and the amplitude often becomes smaller as the frequency becomes higher. Accordingly, it is preferred that suppression be made from a smaller amplitude as the frequency of the band-limited signals becomes higher. The functions shown in Figure 36 serve for this purpose.

The transformation functions shown in Figure 37 are for transforming the band-limited signals to those having values not larger than absolute values of the band-limited signals, which values are determined on the basis of the absolute values of the band-limited signals. As the frequency of the frequency

band to be processed by the function becomes lower, the absolute value of a transformed image signal obtained by transforming a band-limited signal whose absolute value is in a predetermined range near 0 becomes smaller. That is, the functions all pass through the origin and all have inclinations smaller than 1. Further, the inclination near 0 is smaller as the frequency of the frequency band to be processed by the function becomes lower. When an add signal obtained by adding up the transformed image signals is added to the original image signal S_{org}, these functions contribute to smoothen the joint between the original image signal S_{org} and the add signal, that is, rise of the signal.

Similarly transformation by the transformation means 22b in the second transformation section 103b is executed by use of the transformation functions shown in Figure 38 or 37 or combinations of the transformation functions shown in Figures 38 and 37. The transformed image signals output from the first and second transformation sections 103a and 103b are respectively input into operators 123a and 123b. The operator 123a executes operation for making signals necessary for the frequency enhancement processing, and the operator 123b executes operation for making signals necessary for the dynamic range compression processing.

The operator 123a executes a frequency enhancement processing similar to that in the third embodiment described above. That is, the band-limited signals transformed by the first transformation section 103a are added up, and an add signal

thus obtained is multiplied by a coefficient of enhancement β which is determined according to the value of the original image signal S_{org}.

The operator 123b executes a dynamic range compression processing in the following manner. The band-limited signals transformed by the second transformation section 103b are added up, and an add signal thus obtained is subtracted from the original image signal S_{org}. Then the differential signal thus obtained is transformed on the basis of a transformation function, thereby obtaining a coefficient of dynamic range compression.

The signals respectively obtained by the operators 123a and 123b are added to the original image signal S_{org} by an adder 128, whereby a processed image signal S_{proc} is obtained.

The processing described above is represented by the following formula (3).

$$S_{proc}=S_{org}+\beta(S_{org}) \times F_{usm}(S_{org}, \ S_{us}1, \ S_{us}2, \ \cdots\cdots \ S_{us}N)$$

$$+ D\{S_{org}-F_{drc}(S_{org}, \ S_{us}1, \ S_{us}2, \ \cdots\cdots \ S_{us}N)\} \qquad (3)$$

$$F_{usm}(S_{org}, \ S_{us}1, \ S_{us}2, \ \cdots\cdots \ S_{us}N)$$

$$=\{f_{u1}(S_{org}-S_{us}1)+f_{u2}(S_{us}1-S_{us}2)+ \ \cdots$$

$$+ \ f_{uk}(S_{us}k-1-S_{us}k)+ \ \cdots \ +f_{uN}(S_{us}N-1-S_{us}N)$$

$$F_{drc}(S_{org}, \ S_{us}1, \ S_{us}2, \ \cdots\cdots \ S_{us}N)$$

$$=\{f_{d1}(S_{org}-S_{us}1)+f_{d2}(S_{us}1-S_{us}2)+ \ \cdots$$

$$+ \ f_{dk}(S_{us}k-1-S_{us}k)+ \ \cdots \ +f_{dN}(S_{us}N-1-S_{us}N)$$

wherein S_{proc} is a processed image signal, S_{org} is an original image signal, $S_{us}k$ (k=1 to N) is an unsharp image signal, f_{uk}(k=1 to N) is a transformation function used in the first transformation

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section, $f_{dk}(k=1$ to $N)$ is a transformation function used in the second transformation section, $\beta(S_{org})$ is a coefficient of enhancement determined on the basis of the original image signal, and $D\{S_{org}-F_{drc}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)\}$ is a coefficient of dynamic range compression determined on the basis of the low frequency component signal, D being a function for transforming $D\{S_{org}-F_{drc}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)\}$.

In the image processing system shown in Figure 35, the add signal used in the frequency enhancement processing and that used in the dynamic range compression processing are separately obtained on the basis of the original image signal S_{org} and are finally added. However, it is possible to first carry out on one of the frequency enhancement processing and the dynamic range compression processing on the original image signal S_{org} and to carry out the other processing on the resultant signal. Generally the lower density portion of a radiation image includes a relatively large amount of noise since the lower density portion is exposed to less radiation upon taking the radiation image. Since the frequency enhancement processing is a density-dependent processing where the degree of enhancement is increased with increase in density, the low density portion is not enhanced and accordingly noise is not enhanced when the frequency enhancement processing is directly carried out on the original image signal. To the contrast, when the frequency enhancement processing is carried out after the dynamic range compression processing is carried out on the original image

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signal, the low density portion is increased in its density by the dynamic range compression processing, and accordingly, the low density portion is enhanced by the following frequency enhancement processing, whereby noise is also enhanced. Accordingly, it is preferred that each signal be made on the basis of the original image signal S_{org}. Further also from the viewpoint of saving the processing time, it is preferred that the two processings be executed in parallel.

By calculating the transformation functions so that the frequency response characteristic of the processed image signal S_{proc} becomes constant irrespective of resolution of the original image signal S_{org}, the processed image signal S_{proc} can have a substantially constant frequency response characteristic irrespective of the resolution of the original image signal S_{org}.

Though, in the third to fifth embodiments, the transformation functions are calculated by correcting the reference transformation functions on the basis of the resolution of the original image signal S_{org} input, the transformation functions obtained may be further corrected on the basis of information on the response characteristics of the original image signal S_{org}. That is, the original image signal S_{org} is obtained from various apparatuses such as of a semiconductor sensor other than the radiation image read-out apparatus where a radiation image stored on a stimulable phosphor sheet is read out, and the response of the original image signal S_{org} differs by apparatus to apparatus. Accordingly, by

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correcting the transformation functions on the basis of information on the response characteristics of the original image signal S_{org}, a processed image signal S_{proc} having a constant frequency response characteristic can be obtained irrespective of the apparatus by which the original image signal S_{org} is obtained. For example, when the response at 2 cycles/mm of an original image signal S_{org} obtained by a certain apparatus is inferior to a reference response by 40%, the fact is input into the image processing system, and the image processing system corrects the transformation functions so that response at 2 cycles/mm becomes equal to the reference response.

Further, though in the fourth and fifth embodiments described above, non-linear functions are used and a non-linear processing is carried out on the band-limited signals, linear functions or constants may be employed as the transformation functions.

Further, though, in the third to fifth embodiments described above, the unsharp image signals are obtained from the original image signal by filtering and interpolation/enlargement and the band-limited signals are obtained from the original image signal and the unsharp image signals, the band-limited signals may be made, for instance, by transforming the original image signal to multiple resolution image signals by a wavelet transformation or a Laplacian pyramid, making the unsharp image signals from the image signals at the respective resolutions and making the band-limited signals from

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the unsharp image signals.

When the transformation functions for transforming band-limited signals obtained from an original image signal which is different from the reference original image signal in resolution are obtained by correcting the reference transformation functions, it is generally impossible to conform the frequency response characteristic of the processed image signal S_{proc} to the reference processed image signal $S_{proc}0$ (the processed image signal S_{proc} obtained by transforming the band-limited signals from the reference image signal by use of the reference transformation functions) over the entire frequency bands. In an image obtained by reproducing a processed image signal, the low frequency components are visually more prominent than the high frequency components. Accordingly, it is preferred that the transformation functions for band-limited signals for the original image signal to be processed be calculated so that the frequency response characteristic of the processed image signal S_{proc} conforms to that of the reference processed image signal $S_{proc}0$ in frequency bands not lower than 1/5, more preferably not lower than 1/2, of the Nyquist frequency of the original image signal to be processed. For example, when the reference resolution is 5 lines/mm and the resolution of the original image signal S_{org} to be processed is 4 lines/mm, it is preferred that the transformation functions for transforming the band-limited signals obtained from the original image signal S_{org} to be

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processed be calculated on the basis of reference transformation

functions for 5 lines/mm in the following manner.

That is, since the image signal is reduced 1/2 by 1/2 when

a plurality of band-limited signals are obtained, the band-

limited signal in the highest frequency band is at least 1.0

to 2.0 cycles/mm in characteristic width. Accordingly, in the

image processing system in accordance with the third to fifth

embodiments of the present invention, where the gains of the

band-limited signals are controlled by the transformation

functions, it is impossible to finely control the response in

a frequency band between 1.0 and 2.0 cycles/mm and accordingly,

when the frequency response characteristic sharply changes in

the frequency band between 1.0 and 2.0 cycles/mm, it is

impossible to obtain the transformation functions for the 4

lines/mm which can precisely conform the frequency response

characteristic of the processed image signal S_{proc} to that of the

reference processed image signal $S_{proc}0$ in the frequency band

between 1.0 and 2.0 cycles/mm. Accordingly, it is preferred

that the transformation functions for band-limited signals for

the original image signal (at 4 lines/mm) to be processed be

calculated so that the frequency response characteristic of the

processed image signal S_{proc} conforms to that of the reference

processed image signal $S_{proc}0$ in frequency bands not lower than

1/5, more preferably not lower than 1/2, of the Nyquist frequency

of the original image signal to be processed, as shown in Figures

39A and 39B. In Figure 39A, the broken line shows the frequency

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response characteristic of the reference processed image signal $S_{proc}0$ obtained by transforming the band-limited signals from the reference image signal (having a picture element density of 5 lines/mm) by use of reference transformation functions which are set so that relatively low frequency components are enhanced and the solid line shows the frequency response characteristic of the processed image signal S_{proc} obtained by transforming the band-limited signals from the original image signal S_{org} to be processed by use of the transformation functions which are obtained by correcting the reference transformation functions according to the resolution (4 lines/mm) of the original image signal S_{org} to be processed. In Figure 39B, the broken line shows the frequency response characteristic of the reference processed image signal $S_{proc}0$ obtained by transforming the band-limited signals from the reference image signal (having resolution of 5 lines/mm) by use of reference transformation functions which are set so that relatively high frequency components are enhanced and the solid line shows the frequency response characteristic of the processed image signal S_{proc} obtained by transforming the band-limited signals from the original image signal S_{org} to be processed by use of the transformation functions which are obtained by correcting the reference transformation functions according to the resolution (4 lines/mm) of the original image signal S_{org} to be processed.

An image processing system in accordance with a sixth embodiment of the present invention will be described,

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hereinbelow. The image processing system is for carrying out a frequency enhancement processing by use of unsharp image signals on an original image signal obtained by reading out a radiation image of a human body recorded on a stimulable phosphor sheet so that an image suitable for diagnosis can be obtained. An image reproduced on the basis of the processed image signal is mainly recorded on photographic film and used in diagnosis.

In Figure 40, an image processing system 201 in accordance with a sixth embodiment of the present invention comprises an unsharp image signal making means 202 which makes a plurality of unsharp image signals from multiple resolution image signals S_{org}' which are obtained from an original image signal S_{org} by transforming the original image signal S_{org} to multiple resolution space and encoding the transformed image signals, and a frequency enhancement processing means 203 which carries out a frequency enhancement processing for enhancing a particular frequency and obtains an intermediate processed image signal S_{proc}'. The image processing system 201 further comprises a parameter setting means 204, a scale input means 205 and an enlarging/contracting means 206. The parameter setting means 204 is a means which sets transformation functions which the frequency enhancement processing means 203 uses in the frequency enhancement processing on the basis of scale information S input from the scale input means 205. The scale input means 205 is a means for obtaining scale information S on the original image signal S_{org}. The scale information S may

be input as a value by the operator by a keyboard or by the operator

selecting a value from a plurality of scales displayed on a

control screen. The enlarging/contracting means 206 enlarges

or contracts the intermediate processed image signal S_{proc}'

5   obtained by the frequency enhancement processing means 203 on

the basis of the scale information S, thereby making a final

processed image signal S_{proc}.

The original image signal S_{org} is transformed into multiple

resolution space and the transformed image signals are encoded

10   in the following manner. That is, as shown in Figure 41A, the

original image signal S_{org} is subjected to wavelet transformation

and is decomposed into four pieces of data LL1, HL0, LH0 and

HH0 by resolution. The data LL1 represents an image obtained

by reducing the original image to 1/2 in both longitudinal and

15   lateral directions. The data HL0, LH0 and HH0 represents a

longitudinal edge, a lateral edge and an oblique edge. When the

four pieces of data LL1, HL0, LH0 and HH0 are subjected to inverse

wavelet transformation, the original image signal S_{org} is

obtained. Then the data LL1 is further subjected to wavelet

20   transformation and decomposed into four pieces of data LL2, HL1,

LH1 and HH1 as shown in Figure 41B. The data LL2 represents an

image obtained by reducing data LL1 to 1/2 in both longitudinal

and lateral directions. The data HL1, LH1 and HH1 represents

a longitudinal edge component, a lateral edge component and an

25   oblique edge component of the data LL1. When the four pieces

of data LL2, HL1, LH1 and HH1 are subjected to inverse wavelet

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transformation, a low resolution image signal having a resolution equal to 1/2 of that of the original image signal is obtained. Further wavelet transformation is repeated a desired number of times on data LL obtained each time the wavelet transformation is carried out, thereby obtaining a plurality of pieces of data which are different in resolution. Thereafter, data at each resolution is encoded as shown in Figure 41C and the multiple resolution image signals S_{org}' is obtained.

By decoding only image signals up to a desired resolution in the multiple resolution image signals S_{org}' and carrying out inverse wavelet transformation on the image signals, a low resolution image signal representing an image at a resolution of $1/2^k$ (k being the desired resolution) of that of the original image can be obtained.

Making the unsharp image signals will be described, hereinbelow. As shown in Figure 42, the unsharp image signal making means 202 comprises first to n-th filtering means 210. The first filtering means 210 carries out a filtering processing on the original image signal S_{org}, reconstructed from the multiple resolution image signals S_{org}', in x- and y-directions and makes a low resolution image signal B1 which is lower than the original image signal S_{org} in resolution. The second filtering means 210 carries out a similar filtering processing on the low resolution image signal B1 thus obtained and makes a low resolution image signal B2 which is lower than the low resolution image signal B1 in resolution, and the third filtering means 210 carries out

a similar filtering processing on the low resolution image signal B2 thus obtained and makes a low resolution image signal B3 which is lower than the low resolution image signal B3 in resolution. In this manner, the n-th filtering means 210 carries out a similar filtering processing on the low resolution image signal Bn-1 and makes a low resolution image signal Bn which is lower than the low resolution image signal Bn-1 in resolution. The unsharp image signal making means 202 further comprises first to n-th interpolation means 211. The interpolation means 211 carry out an interpolation/enlargement processing on the low resolution image signals B1 to Bn obtained at the respective stages of filtering, and makes a plurality of unsharp image signals $S_{us}k$ ($S_{us}1$ to $S_{us}N$) which are different in sharpness.

In this particular embodiment, filters which substantially conform to one-dimensional Gaussian distribution are used in the filtering processing. That is, coefficients of the filters are determined according the following formula (4) which relates to a Gaussian signal.

$$f(t) = e^{-\frac{t^2}{2\sigma^2}} \qquad (4)$$

This is because the Gaussian signal is good in localization in both a real space and a frequency space. For example, the 5×1 one-dimensional filters are as shown in Figure 43 when σ=1 in formula (4).

The filtering is carried out on the original image signal S_{org} or the low resolution image signals every second picture

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element as shown in Figure 44. When such filtering is carried out in both x- and y- directions, the number of picture elements in obtained low resolution image signal is reduced to 1/4 of the preceding image signal (e.g., the original image signal S_{org} in the case of the low resolution image signal B1, and the low resolution image signal B1 in the case of the low resolution image signal B2). That is, the number of picture elements in each of the low resolution image signals Bk(k stands for 1 to n) is $1/2^k$ of the original image signal S_{org}.

The interpolation/enlargement processing to be carried out on the low resolution image signals Bk thus obtained will be described, hereinbelow. Though various methods of interpolation such as B-spline can be employed, a Gaussian signal is also employed in the interpolation in this particular embodiment since low-pass filters based on Gaussian signals are employed in the filtering processing. Specifically, an approximation, $\sigma=2^{k-1}$, is employed in the following formula (5).

$$I(t) = 2 \cdot \sigma \cdot e^{-\frac{t^2}{2\sigma^2}} \qquad (5)$$

When interpolating the low resolution image signal B1, $\sigma=1$ since k=1. In this case, a one-dimensional filter of 5×1 such as shown in Figure 45 is employed in the interpolation. In this interpolation, a picture element of 0 in value is interpolated every second picture element in the low resolution image signal B1, whereby the low resolution image signal B1 is enlarged to a size equal to the size of the original image, and

the interpolated low resolution image signal B1 is subjected
to a filtering processing using the one-dimensional filter shown
in Figure 45.

This interpolation/enlargement processing is carried out
on all the low resolution image signals Bk (B1 to Bn). When
interpolating a low resolution image signal Bk, a filter which
is $3 \times 2^k - 1$ in length is prepared according to formula (5) and $2^k - 1$
picture elements of 0 in value are interpolated between each
pair of adjacent picture elements, whereby the low resolution
image signal Bk is enlarged to a size equal to the size of the
original image signal. Then the interpolated low resolution
image signal Bk is subjected to a filtering processing using
the filter which is $3 \times 2^k - 1$ in length.

The frequency enhancement processing to be carried out
by use of the unsharp image signals $S_{us}k$ thus obtained will be
described, hereinbelow. Figure 46 shows a system for carrying
out a frequency enhancement processing together with the unsharp
image signal making means 202. As shown in Figure 46, unsharp
image signals $S_{us}k$ are made from the original image signal S_{org}
and differences between the original image signal S_{org} and the
unsharp image signals $S_{us}k$ are taken by respective subtractors
221, whereby band-limited signals ($S_{org}-S_{us}1$, $S_{us}1-S_{us}2$, and the
like) which are components in limited frequency bands of the
original image signal S_{org} are made.

The band-limited signals are transformed to predetermined
amplitudes with different transformation functions f_1 to f_N in

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respective transformation circuits 222 and the transformed band-limited signals are added up and further added to the original image signal S_{org} by an operator 223 according to the following formulae (2′), whereby an intermediate processed image signal S_{proc}′ in which a desired frequency components is enhanced to a required degree is generated.

$$S_{proc}′=S_{org}+\beta(S_{org}) \times F_{usm}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)$$

$$F_{usm}(S_{org}, S_{us}1, S_{us}2, \cdots\cdots S_{us}N)$$

$$=f_1(S_{org}-S_{us}1)+f_2(S_{us}1-S_{us}2)+ \cdots$$

$$+ f_k(S_{us}k-1-S_{us}k)+ \cdots +f_N(S_{us}N-1-S_{us}N) \qquad (2′)$$

wherein S_{proc}′ is an intermediate processed image signal in which the high-frequency components are enhanced, S_{org} is an original image signal, $S_{us}k$ (k=1 to N) are unsharp image signals, f_k(k=1 to N) is a transformation function, and $\beta(S_{org})$ is a coefficient of enhancement determined on the basis of the original image signal.

The intermediate processed image signal S_{proc}′ is thus made. The problem to be solved by this embodiment and the manner of solving the problem in this embodiment will be described through an example, hereinbelow. As described above, though an intermediate processed image signal S_{proc}′ representing an image equivalent to the original image signal in resolution (either may be the same image as the original image or an image different from the original image) can be obtained by carrying out frequency enhancement processing by use of transformation functions f_k determined according to the frequency bands of the

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band-limited signals, an intermediate processed image signal S_{proc}' representing an image lower than the original image signal in resolution (either may be the same image as the original image or an image different from the original image) must be obtained by carrying out frequency enhancement processing by use of transformation functions f_k determined according to the resolution of the intermediate processed image signal S_{proc} to be obtained. When such transformation functions are stored for the respective resolutions, the number of transformation functions to be stored becomes too large and management of the transformation functions becomes to troublesome. When the frequency enhancement processing is carried out on an original image signal S_{org} with the original image signal S_{org} divided into six frequency bands, the frequency characteristics of the band-limited signals have six peaks as shown in Figure 47. The frequencies of the respective peaks are 5 cycles/mm, 1.0 cycle/mm, 0.5 cycles/mm, 0.25 cycles/mm, 0.12 cycles/mm and 0.06 cycles/mm. In an image signal representing an image whose resolution is 1/2 of that of the original image, the peak frequencies of the band-limited signals are 2.5 cycles/mm, 0.5 cycles/mm, o.25 cycles/mm, 0.125 cycles/mm and 0.06 cycles/mm as shown in Figure 48. Further as shown in Figures 49 to 51, in image signals representing image whose resolutions are respectively 1/4, 1/8 and 1/16 of that of the original image, the peak frequencies of the band-limited signals are equal to each other except their respective highest frequency bands.

In this embodiment, when a processed image signal representing an image having a desired resolution lower than the resolution of the original image is to be obtained, one of the low resolution signals representing a low resolution image closest to the desired resolution is employed as a reference low resolution image signal, low resolution band-limited signals are obtained on the basis of the reference low resolution image signal, and the low resolution band-limited signals are transformed into transformed image signals on the basis of transformation functions corresponding to the frequency bands of the band-limited signals, whereby an intermediate processed image signal S_{proc}' is obtained. Then the intermediate processed image signal S_{proc}' is enlarged or contracted according to the scale information S and a processed image signal S_{proc} representing an image having the desired resolution is obtained.

Operation of the image processing system 201 of this embodiment when a processed image signal S_{proc} representing an image whose resolution is 1/2 of the original image signal is to be obtained will be described by way of example with reference to the flow chart shown in Figure 52. It is assumed here that the band-limited signals obtained from the original image signal S_{org} are in six frequency bands as shown in Figure 47.

The user first inputs a desired scale through the scale input means 205. (step S21) Then the scale input means 205 inputs a scale information S into the unsharp image signal making means 202, the parameter setting means 204 and the

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enlarging/contracting means 206, and the unsharp image signal making means 202 reconstructs, on the basis of the scale information S, a low resolution image signal representing an image having a resolution closest to the desired scale in the low resolution image signals B_k (step S22), and makes low resolution unsharp image signals $S_{us}k$ from the low resolution image signals (step S23). In this example, since the resolution of the image represented by the processed image signal S_{proc} to be obtained (to be referred to as "the desired resolution", hereinbelow) is 1/2 of that of the image represented by the original image signal S_{org}, unsharp image signals $S_{us}1$ to $S_{us}5$ are made. The correspondence between the unsharp image signals obtained from the original image signal S_{org} (including the original image signal S_{org}) and those obtained from a given low resolution image signal is as shown in Figure 53. As can be seen from Figure 53, in the case where the desired resolution is 1/2 of that of the original image, unsharp image signals $S_{us}k$ are made with the unsharp image signal $S_{us}1$ which is at the highest hierarchical level in the unsharp image signals obtained from the reference original image signal S_{org} taken as an original image signal $S_{org1/2}$. Accordingly, in this case, the low resolution original image signal $S_{org1/2}$ corresponds to the unsharp image signal $S_{us}1$ obtained from the reference original image signal S_{org}, the unsharp image signals $S_{us}1_{1/2}$ corresponds to the unsharp image signals $S_{us}2$ obtained from the reference original image signal S_{org}, the unsharp image signals $S_{us}2_{1/2}$ corresponds to the

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unsharp image signals $S_{us}3$ obtained from the reference original

image signal S_{org}, and so on. Then low resolution band-limited

signals are made on the basis of the original image signal $S_{org1/2}$

and the low resolution unsharp image signals $S_{us}1_{1/2}$ to $S_{us}5_{1/2}$.

5   (step S24) The correspondence between the band-limited signals

obtained from the reference original image signal S_{org} and those

obtained from a given low resolution image signal is as shown

in Figure 54. Since even if the band-limited signals not higher

than 0.06 cycles/mm are processed, the processed image signal

10   S_{proc} is not substantially improved in quality, the low frequency

band-limited signals not higher than 0.06 cycles/mm are not

processed.

The parameter setting means 204 sets the transformation

functions f_k for transforming the low resolution band-limited

15   signals. (step S25) Since the peak frequencies of the low

resolution band-limited signals are equal to the band-limited

signals obtained from the reference original image signal S_{org}

except their respective highest frequency bands as shown in

Figures 47 and 48, transformation functions f_2 to f_6 are employed.

20   The correspondence between the transformation functions for the

band-limited signals obtained from the reference original image

signal S_{org} and those for the band-limited signals obtained from

a given low resolution image signal is as shown in Figure 55.

When the desired resolution is $1/2^n$ of the resolution of the

25   reference original image signal, the transformation functions

on the line lower than the transformation functions for the

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reference original image signal S_{org} by n lines in Figure 55 are employed. The following formula (14) represents Fusm in the aforesaid formulae (2') in carrying out frequency enhancement processing on the reference original image signal S_{org} and the following formula (15) represents Fusm in the aforesaid formulae (2') in carrying out frequency enhancement processing on the original image signal $S_{org1/2}$ at a resolution of 1/2 of that of the reference original image signal S_{org}.

$$F_{usm}(S_{org}, \ S_{us}1, \ S_{us}2, \ \cdots\cdots \ S_{us}6)$$

$$= f_1(S_{org}-S_{us}1)+f_2(S_{us}1-S_{us}2)+ \ \cdots$$

$$+ \ f_5(S_{us}4-S_{us}5)+f_6(S_{us}5-S_{us}6) \qquad (14)$$

$$F_{usm}(S_{org1/2}, \ S_{us}1_{1/2}, \ S_{us}2_{1/2}, \ \cdots\cdots \ S_{us}5_{1/2})$$

$$= f_1(S_{org1/2}-S_{us}1_{1/2})+f_2(S_{us}1_{1/2}-S_{us}2_{1/2})+ \ \cdots$$

$$+ \ f_4(S_{us}3-S_{us}4)+f_5(S_{us}4-S_{us}5) \qquad (15)$$

Then low resolution transformed image signals are made from the low resolution band-limited signals (step S26), and a low resolution add signal is obtained. Then the low resolution add signal is multiplied by the coefficient of enhancement $\beta(S_{org1/2})$ and the product is added to the low resolution original image signal $S_{org1/2}$, whereby a low resolution intermediate processed image signal $S_{proc1/2}'$ is obtained. The coefficient of enhancement $\beta(S_{org1/2})$ is set according to the low resolution original image signal $S_{org1/2}$.

The low resolution intermediate processed image signal $S_{proc1/2}'$ thus obtained is input into the enlarging/contracting means 206, and the enlarging/contracting means 206 enlarges or

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contracts the low resolution intermediate processed image

signal $S_{proc1/2}'$ on the basis of the scale information S input from

the scale input means 205 so that a low resolution image can

be reproduced at the desired scale, thereby obtaining a final

5   low resolution processed image signal $S_{proc1/2}$. In this particular

example, since the desired resolution is 1/2, the

enlarging/contracting means 206 need not enlarge or contract

the low resolution intermediate processed image signal $S_{proc1/2}'$.

As can be understood from the description above, since,

10   in this embodiment, the low resolution band-limited signals

obtained from the low resolution original image signal are

transformed on the basis of a part of the transformation

functions for transforming the band-limited signals obtained

from the reference original image signal which correspond to

15   the low resolution band-limited signals in frequency bands, the

image reproduced on the basis of the low resolution processed

image signal $S_{proc1/2}$ substantially conforms in frequency response

characteristic to the image reproduced on the basis of the

processed image signal S_{proc} obtained from the reference original

20   image signal, whereby a processed image signal which can

reproduce an image which is substantially constant in frequency

response characteristic irrespective of resolution can be

obtained.

Further since a part of the transformation functions which

25   are employed for frequency enhancement processing of the

reference original image signal are employed, transformation

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functions need not be prepared for each resolution, which simplifies the arrangement of the image processing system and saves trouble to manage a large number of transformation functions.

When an image signal at a desired resolution is obtained by contracting a processed image signal S_{proc} obtained from the reference original image signal S_{org}, making unsharp image signals, making band-limited signals and transformation of the band-limited signals must be carried out using all the low resolution image signals. To the contrast, in this embodiment, since only the low resolution image signals up to that representing an image having a resolution closest to the desired resolution have to be reconstructed, operation time required for the processing can be shortened.

Further, though, in the sixth embodiment described above, the unsharp image signals are obtained from the original image signal (the reference original image signal or the low resolution original image signal) by filtering and interpolation/enlargement and the band-limited signals are obtained from the original image signal and the unsharp image signals, the band-limited signals may be made, for instance, by transforming the original image signal to multiple resolution image signals by a wavelet transformation or a Laplacian pyramid, making the unsharp image signals from the image signals at the respective resolutions and making the band-limited signals from the unsharp image signals.

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Though, in the sixth embodiment described above, frequency enhancement processing is carried out on the encoded multiple resolution image signals S_{org}', the frequency enhancement processing may be carried out on an original image signal S_{org} which is not encoded.

An image processing system in accordance with a seventh embodiment of the present invention will be described, hereinbelow. In the sixth embodiment, low resolution image signals up to the resolution closest to a desired resolution are reconstructed from an encoded multiple resolution image signals S_{org}' and unsharp image signals are made on the basis of the reconstructed low resolution image signals. To the contrast, in the seventh embodiment, unsharp image signals are made on the basis of low resolution image signals from the lowest resolution to a resolution closest to the resolution corresponding to a desired scale. The seventh embodiment differs from the sixth embodiment only in the processing executed by the unsharp image signal making means, and accordingly the processing executed by the unsharp image signal making means in this embodiment will be mainly described, hereinbelow.

Figure 56 shows a unsharp image signal making means 202' in the image processing system of the seventh embodiment. As shown in Figure 56, the unsharp image signal making means 202' comprises a plurality of encoders 230 and a plurality of interpolation means 231. That is, a low resolution image signal B_n representing an image at a resolution of $1/2^n$ of that of the

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original image represented by the reference original image signal S_{org} is first made by decoding an image signal representing an image which the lowest in resolution in the images represented by the multiple resolution image signals S_{org}' and carrying out an inverse wavelet transformation on the decoded image signal. Then a low resolution image signal B_{n-1} representing an image at a resolution of $1/2^{n-1}$ of that of the original image is made on the basis of the low resolution image signal B_n. In this manner, low resolution image signals B_k whose resolution are $1/2^k$ ($k=1$ to n) of that of the original image signal S_{org} are made as well as the original image signal S_{org}. The low resolution signals B_k correspond to data LLk obtained by carrying out a wavelet transformation on the original image signal S_{org}. Then the interpolation means 231 carries out an interpolation/enlargement processing on each of the low resolution image signal B_k and a plurality of unsharp image signals $S_{us}k$ ($k=1$ to N) which are different in sharpness are made.

Then band-limited signals are obtained from the unsharp image signals $S_{us}k$ and an intermediate processed image signal S_{proc}' is obtained according to the aforesaid formulae (2').

Operation of the image processing system of this embodiment when a processed image signal S_{proc} representing an image whose resolution is 1/2 of the original image signal is to be obtained will be described by way of example. It is assumed here that the band-limited signals obtained from the original image signal S_{org} are in six frequency bands.

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The user first inputs a desired scale through the scale input means 205. Then the scale input means 205 inputs a scale information S into the unsharp image signal making means 202', the parameter setting means 204 and the enlarging/contracting means 206, and the unsharp image signal making means 202' reconstructs, on the basis of the scale information S, low resolution image signals B_k from the lowest resolution to a resolution closest to the resolution corresponding to the desired scale and makes low resolution unsharp image signals $S_{us}k$. In this example, since the resolution of the image represented by the processed image signal S_{proc} to be obtained (to be referred to as "the desired resolution", hereinbelow) is 1/2 of that of the image represented by the original image signal S_{org}, unsharp image signals $S_{us}1$ to $S_{us}5$ are made. The correspondence between the unsharp image signals obtained from the original image signal S_{org} (including the original image signal S_{org}) and those obtained from the low resolution image signals B_k from the lowest resolution to a resolution closest to the resolution corresponding to the desired scale is as shown in Figure 53. The correspondence between the band-limited signals obtained from the reference original image signal S_{org} and those obtained from the low resolution image signals B_k from the lowest resolution to a resolution closest to the resolution corresponding to the desired scale is as shown in Figure 54.

The parameter setting means 204 sets the transformation functions f_k for transforming the low resolution band-limited

signals in the same manner as in the sixth embodiment. When the desired resolution is $1/2^n$ of the resolution of the reference original image signal, the transformation functions on the line lower than the transformation functions for the reference original image signal S_{org} by n lines in Figure 55 are employed.

Then low resolution transformed image signals are made from the low resolution band-limited signals, and a low resolution add signal is obtained. Then the low resolution add signal is multiplied by the coefficient of enhancement $\beta(S_{org1/2})$ and the product is added to the low resolution original image signal $S_{org1/2}$, whereby a low resolution intermediate processed image signal $S_{proc1/2}{}'$ is obtained.

The low resolution intermediate processed image signal $S_{proc1/2}{}'$ thus obtained is input into the enlarging/contracting means 206, and the enlarging/contracting means 206 enlarges or contracts the low resolution intermediate processed image signal $S_{proc1/2}{}'$ on the basis of the scale information S input from the scale input means 205 so that a low resolution image can be reproduced at the desired scale, thereby obtaining a final low resolution processed image signal $S_{proc1/2}$. In this particular example, since the desired resolution is 1/2, the enlarging/contracting means 206 need not enlarge up or contract the low resolution intermediate processed image signal $S_{proc1/2}{}'$.

As can be understood from the description above, since, also in this embodiment, the low resolution band-limited signals obtained from the low resolution original image signal are

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transformed on the basis of a part of the transformation functions for transforming the band-limited signals obtained from the reference original image signal which correspond to the low resolution band-limited signals in frequency bands, the image reproduced on the basis of the low resolution processed image signal $S_{proc1/2}$ substantially conforms in frequency response characteristic to the image reproduced on the basis of the processed image signal S_{proc} obtained from the reference original image signal, whereby a processed image signal which can reproduce an image which is substantially constant in frequency response characteristic irrespective of resolution can be obtained.

Though, the above description has been made by way of example on the case where the desired resolution is 1/2 of that of the reference original image signal, in the case where the desired resolution is, for instance, 1/3 of that of the reference original image signal, the unsharp image signal making means 202 and the frequency enhancement processing means 203 carry out the frequency enhancement processing on the low resolution image signal B_2 representing an image whose resolution (1/4 of the original image signal) is closest to 1/3, thereby making an intermediate processed image signal $S_{proc1/4}'$. Then a final processed image signal $S_{proc1/4}$ is obtained by enlarging the intermediate processed image signal $S_{proc1/4}'$ 4/3 times by the enlarging/contracting means 206. When the desired resolution is $1/2^n$ of that of the original image, the enlarging/contracting

means 206 may be eliminated, whereby the system can be simplified.

Though, in the sixth and seventh embodiments, the transformed image signals are made by transforming the band-limited signals on the basis of the transformation functions f_k according to the aforesaid formulae (2'), the transformed image signals may be obtained by enhancing the band-limited signals by use of coefficients of enhancement α_k (k stands for 1 to N) in place of the transformation functions f_k as represented by the following formulae (16).

$$S_{proc}' = S_{org} + \beta(S_{org}) \times F_{usm}(S_{org}, S_{us}1, S_{us}2, \cdots S_{us}N)$$

$$F_{usm}(S_{org}, S_{us}1, S_{us}2, \cdots S_{us}N)$$

$$= \alpha_1(S_{org} - S_{us}1) + \alpha_2(S_{us}1 - S_{us}2) + \cdots$$

$$+ \alpha_k(S_{us}k-1 - S_{us}k) + \cdots + \alpha_N(S_{us}N-1 - S_{us}N) \qquad (16)$$

When an original image signal to be processed is higher than the reference original image signal S_{org} in resolution, the number of the band-limited signals and the number of the transformation functions for transforming the band-limited signals are larger than those for the reference original image signal S_{org}. Figure 57 shows the correspondence between the band-limited signals obtained from the reference original image signal S_{org} and those obtained from original image signals which are twice and four times the reference original image signal S_{org} in resolution. When the object original image signal to be processed has a resolution twice that of the reference original image signal S_{org} (this object original image signal is denoted

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by S_{org2} in Figure 57, and the unsharp image signals obtained from the object original image signal S_{org2} are denoted by $S_{us2}k$ (k stands for an integer larger than 0)), there is no band-limited signal, in the band-limited signals obtained from the reference original

5   image signal S_{org}, corresponding to band-limited signal $S_{org2}-S_{us2}1$ in the highest frequency band in the band-limited signals obtained from the object original image signal S_{org2}, and accordingly there is no transformation function for transforming the band-limited signal $S_{org2}-S_{us2}1$ in the reference

10   transformation functions for transforming the band-limited signals obtained from the reference original image signal S_{org}. Similarly when the object original image signal to be processed has a resolution four times that of the reference original image signal S_{org} (this object original image signal is denoted by S_{org4}

15   in Figure 57, and the unsharp image signals obtained from the object original image signal S_{org4} are denoted by $S_{us4}k$ (k stands for an integer larger than 0)), there is no band-limited signal, in the band-limited signals obtained from the reference original image signal S_{org}, corresponding to band-limited signals $S_{org4}-S_{us4}1$

20   and $S_{us4}1- S_{us4}2$ in the highest and second highest frequency bands in the band-limited signals obtained from the object original image signal S_{org4}, and accordingly there is no transformation function for transforming the band-limited signals $S_{org4}-S_{us4}1$ and $S_{us4}1- S_{us4}2$ in the reference transformation functions for

25   transforming the band-limited signals obtained from the reference original image signal S_{org}.   In such cases, the

transformation function f1 for the band-limited signal $S_{org}-S_{us}1$ in the highest frequency band in the band-limited signals obtained from the reference original image signal S_{org} is used as the transformation functions for transforming the band-

5   limited signal(s) in the highest and second highest frequency bands obtained from the object original image signal as shown in Figure 58.

When there are prepared a plurality of reference original image signals S_{org}, it is preferred that one of the reference

10   original image signal S_{org} closest to the object original image signal in resolution be taken as the reference original image signal S_{org} in the manner described above in conjunction with the first and second embodiments. It is preferred that the transformation functions which are determined for the band-

15   limited signals obtained from the object original image signal be related to the object original image signal and stored together with the resolution of the reference original image signal. With this arrangement, the image represented by the object original image signal can be constantly reproduced with

20   the same characteristic.

An image processing system in accordance with a seventh embodiment of the present invention will be described, hereinbelow. The image processing system is for carrying out a frequency enhancement processing by use of unsharp image

25   signals on an original image signal obtained by reading out a radiation image of a human body recorded on a stimulable phosphor

sheet so that an image suitable for diagnosis can be obtained. An image reproduced on the basis of the processed image signal is mainly recorded on photographic film and used in diagnosis.

In Figure 59, an image processing system 301 in accordance with the seventh embodiment of the present invention comprises a picture element density transformation means 304, an unsharp image signal making means 302, a frequency enhancement processing means 303, an enlarging/contracting means 305 and a parameter correcting means 306. When frequency enhancement processing is to be carried out on an original image signal S_{org} itself, the picture element density transformation means 304 passes the original image signal S_{org} as it is to the unsharp image signal making means 302 which makes a plurality of unsharp image signals from the original image signal S_{org}. The unsharp image signal making means 302 inputs the unsharp image signals into the frequency enhancement processing means 303. The frequency enhancement processing means 303 carries out the frequency enhancement processing for enhancing a particular frequency to obtain an intermediate processed image signal S_{proc}' and inputs the intermediate processed image signal S_{proc}' into the enlarging/contracting means 305. In this case, the enlarging/contracting means 305 outputs the intermediate processed image signal S_{proc}' as it is as a final processed image signal S_{proc}. To the contrast, when the frequency enhancement processing is to be carried out on an original image signal S_{org} which is obtained by picture element density transformation of

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a base original image signal S_{org}' which is read out by an image

read-out apparatus or the like and has a reference predetermined

picture element density (10 lines/mm in this particular

embodiment), the picture element density transformation means

5   304 transforms the picture element density of the base original

image signal S_{org}' to a desired picture element density, e.g.,

6.7 lines/mm or 5 lines/mm, thereby obtaining an original image

signal S_{org} at the desired picture element density. Then the

picture element density transformation means 304 inputs the

10   picture element density-transformed original image signal S_{org}

into the unsharp image signal making means 302. The unsharp

image signal making means 302 makes a plurality of unsharp image

signals from the original image signal S_{org} and inputs the unsharp

image signals into the frequency enhancement processing means

15   303. The frequency enhancement processing means 303 carries out

the frequency enhancement processing for enhancing a particular

frequency to obtain an intermediate processed image signal S_{proc}'

and inputs the intermediate processed image signal S_{proc}' into

the enlarging/contracting means 305. In this case, the

20   enlarging/contracting means 305 enlarges the intermediate

processed image signal S_{proc}' by interpolation at a desired

magnification and outputs the enlarged intermediate processed

image signal S_{proc}' as a final processed image signal S_{proc}. In

this specification, the term "magnification" should be broadly

25   interpreted to include a magnification smaller than 1. The

desired picture element density may be input through a keyboard

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or the like as a value or may be selected from a plurality of picture element densities displayed on a control screen. Similarly the desired magnification may be input through a keyboard or the like as a value or may be selected from a plurality

5   of magnifications displayed on a control screen.

The picture element density transformation processing will be described, hereinbelow. In the aforesaid radiation image read-out system using a stimulable phosphor sheet, the read density or the picture element density differs depending on the size of the stimulable phosphor sheet and may be freely changed as required by the user. In this embodiment, a base original image signal S_{org}' read at 10 lines/mm is transformed to an original image signal S_{org} at 6.7 lines/mm or 5 lines/mm by carrying out a filtering processing on the base original image signal S_{org}' by the picture element density transformation means 304. In this specification, the original image signal S_{org} obtained by carrying out the picture element density transformation on the base original image signal S_{org}' will be referred to as "the picture element density-transformed original image signal S_{org}", hereinbelow, in order to clearly distinguish the former from the latter.

The unsharp image signal making means 302 makes unsharp image signals $S_{us}k$ in the same manner as described above and the frequency enhancement processing means 303 carries out the frequency enhancement processing by use of the unsharp image signals $S_{us}k$ in the same manner as described, whereby the

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intermediate processed image signal S_{proc}' is obtained.

The enlarging/contracting means 305 enlarges the intermediate processed image signal S_{proc}' by interpolation using an interpolation filter at a desired magnification, thereby obtaining a final processed image signal S_{proc}.

Desired frequency components of the original image signal S_{org} can be enhanced by thus carrying out on the original image signal S_{org} a frequency enhancement processing by use of transformation functions f_k which are set for the respective frequency bands of the band-limited signals. However, when the frequency enhancement processing is carried out on the picture element density-transformed original image signal S_{org} by use of the same transformation functions f_k as those used for carrying out the frequency enhancement processing on the base original image signal S_{org}', the image reproduced on the basis of the processed image signal S_{proc} obtained from the picture element density-transformed original image signal S_{org} becomes different in frequency response characteristic from that reproduced on the basis of the processed image signal S_{proc} obtained from the base original image signal S_{org}' and the former image becomes less sharp than the latter image though the images are the same in size. This is due to the picture element density transformation which is carried out when the picture element density-transformed original image signal S_{org} is obtained and the interpolation processing carried out to enlarge the intermediate processed image signal S_{proc}'.

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Accordingly, in this embodiment, the transformation functions f_k for transforming the band-limited signals obtained from the picture element density-transformed original image signal S_{org} are obtained by correcting the parameters of the transformation functions f_k for transforming the band-limited signals obtained from the base original image signal S_{org}' according to the filtering characteristic F1 of the picture element density transformation filter which is employed to carry out the picture element density transformation processing by the picture element density transformation means 304 and the filtering characteristic F2 of an interpolation filter which is employed to carry out the interpolation by the enlarging/contracting means 305 so that the frequency response characteristic of the image reproduced on the basis of the processed image signal S_{proc} obtained from the picture element density-transformed original image signal S_{org} becomes equal to that reproduced on the basis of the processed image signal S_{proc} obtained from the base original image signal S_{org}'.

Correction of the parameters of the transformation functions by the parameter correcting means 306 will be described, hereinbelow. In the description below,

Figure 60 shows the filtering characteristic F1 of the picture element density transformation filter which is employed by the picture element density transformation means 304 to transform the base original image signal S_{org}' having a picture element density of 10 lines/mm to an picture element

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density-transformed original image signal S_{org} having a picture

element density of 5 lines/mm, and Figure 61 shows the filtering

characteristic F2 of the interpolation filter which is employed

by the enlarging/contracting means 305 to double the picture

element density-transformed original image signal S_{org}. The

picture element density-transformed original image signal S_{org}

obtained by transforming, by use of the picture element density

transformation filter whose filtering characteristic is F1, the

base original image signal S_{org}' having a picture element density

of 10 lines/mm to an picture element density-transformed

original image signal S_{org} having a picture element density of

5 lines/mm will be referred to as "the 5-line transformed

original image signal $S_{org}5$" hereinbelow. Figure 62 shows the

frequency response characteristic of the processed image signal

S_{proc} obtained by carrying out the frequency enhancement

processing by use of the transformation functions f_k set for the

frequency enhancement processing of the base original image

signal S_{org}' (these transformation functions will be referred to

as "the base transformation functions f_{kb}" hereinbelow) on the

5-line transformed original image signal $S_{org}5$ and by doubling

the obtained intermediate processed image signal S_{proc}' by use

of the interpolation filter whose filtering characteristic is

F2. The processed image signal S_{proc} thus obtained from the 5-line

transformed original image signal $S_{org}5$ will be referred to as

"the 5-line processed image signal $S_{proc}5$" hereinbelow. Further

the processed image signal S_{proc} obtained by frequency-enhancing

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the base original image signal S_{org}' by use of the base

transformation functions f_{kb} will be referred to as the "the base

processed image signal $S_{proc}B$", hereinbelow. In Figure 62, the

frequency response characteristic of the 5-line processed image

signal $S_{proc}5$ is shown with the frequency response characteristic

of the base processed image signal $S_{proc}B$ taken as 1. As can be

seen from Figure 62, the frequency response characteristic of

the 5-line processed image signal $S_{proc}5$ can be easily calculated

on the basis of the filtering characteristic F1 of the picture

element density-transformation filter and the filtering

characteristic F2 of the interpolation filter. Further, the

difference in frequency response characteristic between the

base processed image signal $S_{proc}B$ and the 5-line processed image

signal $S_{proc}5$ can be easily obtained from Figure 62.

For example, in order to equalize aspect of the image

reproduced on the basis of the 5-line processed image signal

$S_{proc}5$ to that of the image reproduced on the basis of the base

processed image signal $S_{proc}B$ at 2 cycles/mm, it is necessary to

double the frequency response at 2 cycles/mm of the 5-line

processed image signal $S_{proc}5$. Accordingly, in this embodiment,

the transformation function for the band-limited signal in the

frequency band corresponding to 2 cycles/mm is set by correcting

the parameters for the base transformation function f_{kb} for the

band-limited signal in the frequency band corresponding to 2

cycles/mm so that the degree of enhancement is doubled. As shown

in Figure 63, the band-limited signal in the frequency band

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corresponding to 2 cycles/mm is in the highest frequency band, and accordingly the parameter of the transformation function f_1 for the band-limited signal in the highest frequency band is corrected so that the degree of enhancement is doubled. More specifically, when the transformation function is a function having an inclination, the inclination is doubled, and when the transformation function is a constant, the value of the constant is doubled. The frequency component at which aspect of the image reproduced on the basis of the 5-line processed image signal $S_{proc}5$ is to be equalized to that of the image reproduced on the basis of the base processed image signal $S_{proc}B$ may be any frequency and may be two or more frequencies. Further the frequency component may be input by the user through an input means not shown.

Operation of the image processing of this embodiment will be described with reference to the flow chart shown in Figure 64, hereinbelow. It is assumed that a 5-line processed image signal $S_{proc}5$ is obtained by transforming a base original image signal S_{org}' having a picture element density of 10 lines/mm to a 5-line transformed original image signal $S_{org}5$ having a picture element density of 5 lines/mm, carrying out the frequency enhancement processing on the 5-line transformed original image signal $S_{org}5$, thereby obtaining an intermediate processed image signal S_{proc}', and doubling the intermediate processed image signal S_{proc}'. The base original image signal S_{org}' is first input into the image processing system 301. (step S31) Then the

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picture element density transformation means 304 transforms the base original image signal S_{org}' to the 5-line transformed original image signal $S_{org}5$. (step S32) The 5-line transformed original image signal $S_{org}5$ is input into the unsharp image signal making means 302 and the unsharp image signal making means 302 makes unsharp image signals $S_{us}k$ from the 5-line transformed original image signal $S_{org}5$. (step S33) The filtering characteristics F1 and F2 are input into the parameter correcting means 306. Further information on the frequency component at which aspect of the image reproduced on the basis of the 5-line processed image signal $S_{proc}5$ is to be equalized to that of the image reproduced on the basis of the base processed image signal $S_{proc}B$ is input into the parameter correcting means 306 (the frequency component will be referred to as "the target frequency component", hereinbelow). (step S34) The parameter correcting means 306 corrects the parameters of the base transformation functions f_{kb} on the basis of the filtering characteristics F1 and F2 and the information on the target frequency component. (step S35) Steps S4 and S5 may be executed before steps S2 and S3 or in parallel thereto.

Then the frequency enhancement processing means 303 makes band-limited signals on the basis of the unsharp image signals $S_{us}k$ and carries out the frequency enhancement processing on the unsharp image signals $S_{us}k$ by use of the transformation functions defined by the corrected parameters, thereby obtaining the intermediate processed image signal S_{proc}'. (step S36) Then the

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enlarging/contracting means 305 enlarges the intermediate

processed image signal S_{proc}', thereby obtaining the final 5-

line processed image signal $S_{proc}5$. (step S37) Finally, an image

is reproduced by a printer or the like on the basis of the 5-line

5   processed image signal $S_{proc}5$. (step S38)

Thus, in this embodiment, the parameters of the

transformation functions for carrying out the frequency

enhancement processing on the picture element density-

transformed original image signal S_{org} are determined by

10   correcting the parameters of the base transformation functions

f_{kb} (the transformation functions for carrying out the frequency

enhancement processing on the base original image signal S_{org}')

on the basis of the filtering characteristics F1 and F2 so that

the frequency response characteristic of the processed image

15   signal S_{proc} becomes substantially equal to that of the base

processed image signal $S_{proc}B$, and accordingly the image

reproduced on the basis of the processed image signal S_{proc}

obtained from the picture element density-transformed original

image signal S_{org} can be equivalent in sharpness to the image

20   reproduced on the basis of the base processed image signal $S_{proc}B$

obtained from the base original image signal S_{org}'. Further since

the frequency response characteristic is corrected

simultaneously with the frequency enhancement processing, the

operation time can be saved as compared with when correction

25   of the frequency response characteristic is carried out on the

processed image signal S_{proc} which has been subjected to the

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frequency enhancement processing.

Though, in the seventh embodiment, the parameters of the base transformation functions f_{kb} are corrected according to the filtering characteristic F1 of the picture element density-transformation filer and the filtering characteristic F2 of the interpolation filter, it is possible to prepare in advance a table in which the kind of the picture element density transformation to be carried out by the picture element density transformation means 304 and the kind of the interpolation filter to be used by the enlarging/contracting means 305 are related to the degree of correction of the parameters and to correct the parameters with reference to the table on the basis of the picture element density, the magnification and the target frequency component input from the input means.

Further though, in the seventh embodiment, the frequency response characteristic of the 5-line processed image signal $S_{proc}5$ is obtained on the basis of the filtering characteristics F1 and F2 shown in Figures 58 and 59 and the parameters of the transformation function for transforming the band-limited signal corresponding to the target frequency component are corrected so that frequency response of the processed image signal S_{proc} obtained from the 5-line transformed original image signal $S_{org}5$ becomes equal to that of the base processed image signal $S_{proc}B$, when the filtering characteristics F1 and F2 are represented by formulae, the frequency response characteristic of the 5-line processed image signal $S_{proc}5$ may be obtained on

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the basis of the formulae.

Further, though, in the seventh embodiment, the base original image signal S_{org}' is transformed to the picture element density-transformed original image signal S_{org} by filtering the base original image signal S_{org}' by use of a picture element density-transformation filter, the base original image signal S_{org}' may be transformed to the picture element density-transformed original image signal S_{org} by other various methods. For example, linear interpolation or spline interpolation or thinning of picture elements after filtering may be employed. In such a case, the frequency response characteristic of the picture element density-transformed original image signal S_{org} is calculated on the basis of the coefficient of contraction by the interpolation, or by Fourier transformation of the picture element density-transformed original image signal S_{org}, and the parameters of the base transformation functions f_{kb} are corrected on the basis of the frequency response characteristic.

Also when a processed image signal S_{proc} is obtained by enlarging an intermediate processed image signal S_{proc}' obtained from the base original image signal S_{org}' as it is by the enlarging/contracting means 305, or when a processed image signal S_{proc} is obtained from a picture element density-transformed original image signal S_{org} without enlarging the intermediate processed image signal S_{proc}', the processed image signal S_{proc} can differ in frequency response characteristic from the base processed image signal $S_{proc}B$. In such a case, the base

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transformation functions f_{kb} may be corrected on the basis of one of the filtering characteristics F1 and F2.

Further, though, in the seventh embodiment described above, the unsharp image signals are obtained from the original image signal by filtering and interpolation/enlargement and the band-limited signals are obtained from the original image signal and the unsharp image signals, the band-limited signals may be made, for instance, by transforming the original image signal to multiple resolution image signals by a wavelet transformation or a Laplacian pyramid, and the image signals at the respective resolutions may be taken as the band-limited signals.

An image processing system 331 in accordance with an eighth embodiment of the present invention will be described, hereinbelow.

In Figure 65, the image processing system 331 in accordance with the eighth embodiment of the present invention comprises an unsharp image signal making means 332 which makes a plurality of unsharp image signals from multiple resolution image signals S_{org}'' which are obtained from a base original image signal S_{org}' by transforming the base original image signal S_{org}' to multiple resolution space and encoding the transformed image signals, and a frequency enhancement processing means 333 which carries out a frequency enhancement processing for enhancing a particular frequency and obtains an intermediate processed image signal S_{proc}'. The image processing system 331 further comprises an enlarging/contracting means 335 which enlarges the

intermediate processed image signal S_{proc}', and a parameter

correcting means 336. The processing performed by the unsharp

image signal making means 332, the frequency enhancement

processing means 333 and the enlarging/contracting means 335

is the same as that in the seventh embodiment, and accordingly

will not be described here. In this embodiment, the parameter

correcting means 336 corrects the parameters of the base

transformation functions f_{kb} according to the characteristics

of the wavelet transformation functions which are employed when

transforming the original image signal S_{org} to multiple

resolution space.

The base original image signal S_{org}' is transformed into

multiple resolution space and the transformed image signals are

encoded in the following manner. That is, as shown in Figure

66A, the base original image signal S_{org}' is subjected to wavelet

transformation and is decomposed into four pieces of data LL1,

HL0, LH0 and HH0 by resolution. The data LL1 represents an image

obtained by reducing the original image to 1/2 in both

longitudinal and lateral directions. The data HL0, LH0 and HH0

represents a longitudinal edge, a lateral edge and an oblique

edge. When the four pieces of data LL1, HL0, LH0 and HH0 are

subjected to inverse wavelet transformation, the original image

signal S_{org} is obtained. Then the data LL1 is further subjected

to wavelet transformation and decomposed into four pieces of

data LL2, HL1, LH1 and HH1 as shown in Figure 66B. The data LL2

represents an image obtained by reducing data LL1 to 1/2 in both

longitudinal and lateral directions. The data HL1, LH1 and HH1

represents a longitudinal edge component, a lateral edge

component and an oblique edge component of the data LL1. When

the four pieces of data LL2, HL1, LH1 and HH1 are subjected to

5   inverse wavelet transformation, a low resolution image signal

having a resolution equal to 1/2 of that of the original image

signal is obtained. Further wavelet transformation is repeated

a desired number of times on data LL obtained each time the

wavelet transformation is carried out, thereby obtaining a

10   plurality of pieces of data which are different in resolution.

Thereafter, data at each resolution is encoded as shown in Figure

66C and the multiple resolution image signals S_{org}'' is obtained.

By decoding only image signals up to a desired resolution

in the multiple resolution image signals S_{org}'' and carrying out

15   inverse wavelet transformation on the image signals, a low

resolution image signal representing an image at a resolution

of $1/2^k$ (k being the desired resolution) of that of the original

image can be obtained.

As described above, by restoring low resolution image

20   signals up to a desired resolution in the multiple resolution

image signals S_{org}'', a low resolution image signal representing

an image at a resolution of $1/2^k$ (k being the desired resolution)

of that of the original image can be obtained. However, the image

reproduced on the basis of the low resolution image signal

25   becomes unsharp depending on wavelet transformation functions

used in the wavelet transformation. Figure 67 shows frequency

response characteristics of the low resolution image signals which are restored up to a resolution equal to 1/2 of that of the base original image signal S_{org}' and up to a resolution equal to 1/4 of that of the base original image signal S_{org}' when the base original image signal S_{org}' has been decomposed by use of wavelet transformation functions having first coefficients of filter, and Figure 68 shows the same when the base original image signal S_{org}' has been decomposed by use of wavelet transformation functions having second coefficients of filter. As can be seen from Figures 65 and 66, as the response deteriorates, high frequency components deteriorate and the image becomes less sharp. In Figures 65 and 66, the frequency response of the base original image signal S_{org}' is 1 over the entire frequency bands.

The multiple resolution image signals S_{org}'' obtained by decomposing a base original image signal S_{org}' by wavelet transformation are attached with information on the size of the wavelet transformation functions and/or the coefficients of filter thereof since the wavelet transformation functions to be employed in the wavelet transformation should be in one to one correspondence to the wavelet transformation functions to be employed in the inverse wavelet transformation. Accordingly, in the eighth embodiment, when a low resolution image signal at a desired resolution restored from multiple resolution image signals S_{org}'' obtained by decomposing a base original image signal S_{org}' is taken as an object original image signal S_{org}, the difference in response at a target frequency component between

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the processed image signal S_{proc} which is obtained by carrying out the frequency enhancement processing on the object original image signal S_{org} by use of the base transformation functions f_{kb} and the base processed image signal $S_{proc}B$ obtained by carrying out the frequency enhancement processing on the base original image signal S_{org}' by use of the base transformation functions f_{kb} is obtained on the basis of the information on the wavelet transformation functions attached to the multiple resolution image signals S_{org}'' and the parameters of the transformation functions for transforming the object original image signal S_{org} are corrected by the parameter correcting means 336 so that the difference is compensated for. When information on the wavelet transformation functions is not attached to the multiple resolution image signals S_{org}'', the information is manually input into the image processing system 331.

For example, when a low resolution image signal restored up to a resolution equal to 1/4 of that of a base original image signal S_{org} from multiple resolution image signals S_{org}'' obtained by decomposing the base original image signal S_{org}' is taken as an object original image signal S_{org}, aspect of the image reproduced on the basis of the 1/4 resolution image signal at a frequency of 1 cycle/mm is equalized to that of the image reproduced on the basis of the base original image signal S_{org}' in the following manner. The frequency at which aspect of the image reproduced on the basis of the 1/4 resolution image signal is to be equalized to that of the image reproduced on the basis

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of the base original image signal S_{org}' is input in advance through

an input means by the user. Since the response of the image

reproduced on the basis of the 1/4 resolution image signal at

1 cycle/mm is 0.9 whereas the response of the image reproduced

on the basis of the base original image signal S_{org}' at 1 cycle/mm

is 1, it is necessary to multiply the frequency response at 1

cycle/mm of the 1/4 resolution image signal by 1/0.9 in order

to equalize aspect of the image reproduced on the basis of the

1/4 resolution image signal to that of the image reproduced on

the basis of the base original image signal S_{org}' at 1 cycle/mm.

Accordingly, in this embodiment, the transformation function

for the band-limited signal in the frequency band corresponding

to 1 cycle/mm is set by correcting the parameters for the base

transformation function f_{kb} for the band-limited signal in the

frequency band corresponding to 1 cycle/mm so that the degree

of enhancement becomes 1/0.9 times. More specifically, when the

transformation function is a function having an inclination,

the inclination is multiplied by 1/0.9, and when the

transformation function is a constant, the value of the constant

is multiplied by 1/0.9. The frequency component at which aspect

of the image reproduced on the basis of the 1/4 resolution image

signal is to be equalized to that of the image reproduced on

the basis of the base original image signal S_{org}' may be any

frequency and may be two or more frequencies. Further the

frequency component may be input by the user through an input

means not shown.

Thus in this embodiment, when frequency enhancement processing is to be carried out on an image signal which is lower in resolution than a base original image signal S_{org}' and is obtained from multiple resolution image signals S_{org}'' obtained by wavelet transformation of the base original image signal S_{org}', the transformation functions for transforming the band-limited signals obtained from the low resolution image signal are corrected on the basis of the wavelet transformation functions employed in the wavelet transformation of the base original image signal S_{org} so that the image reproduced on the basis of the processed image signal obtained from the low resolution image signal becomes substantially equal to the image reproduced on the basis of the processed image signal obtained from the base original image signal in frequency response characteristic at a desired frequency. Accordingly, a processed image signal which is substantially equal in frequency response characteristic to a processed image signal obtained from the base original image signal can be constantly obtained irrespective of the resolution of the low resolution image signal. Further since the frequency response characteristic is corrected simultaneously with the frequency enhancement processing, the operation time can be saved as compared with when correction of the frequency response characteristic is carried out on the processed image signal S_{proc} which has been subjected to the frequency enhancement processing.

In the case where the processed image signal S_{proc} is to be

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enlarged by the enlarging/contracting means 335 in the eighth

embodiment, the parameters of the base transformation functions

f_{kb} are corrected on the basis of the filtering characteristic

of the filter employed by the enlarging/contracting means 335

5   in addition to the characteristics of the wavelet transformation

functions.

In the seventh and eighth embodiments described above,

it is preferred that the object original image signal S_{org} and

the parameters for the object original image signal S_{org} obtained

10   by correcting the base transformation functions according to

the characteristic of enlargement or the characteristic of

contraction be stored correlated to each other. With this

arrangement, when an image is output (output as a hard copy on

photographic film or displayed on a CRT or the like) again on

15   the basis of the object original image signal S_{org}, an image at

a quality equivalent to that of a previously output image can

be obtained.

Further, it is preferred that the base original image

signal S_{org}' from which the object original image signal S_{org} is

20   obtained,   the   characteristic   of   enlargement   or   the

characteristic of contraction with which the base original image

signal S_{org}' is enlarged or contracted to the object original

image   signal S_{org} and   the   parameters   of   the   reference

transformation functions be stored correlated to each other.

25   With this arrangement, enlarged or contracted images can be

repeatedly reproduced on the basis of the base original image

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signal S_{org}' at the same image quality.

The characteristic of enlargement or the characteristic of contraction may be represented by a space frequency characteristic and may be stored as table data such as shown in Figure 69. Otherwise the space frequency characteristic representing the characteristic of enlargement or the characteristic of contraction may be approximated by a function and parameters of the function may be stored as the characteristic of enlargement or the characteristic of contraction. As such a function, a Gaussian function such as shown below may be employed.

$$Res=exp(-a^2/\sigma^2)$$

wherein a=0 when Fq-m<0 and otherwise a=Fq-m, Res represents the response and Fq represents the space frequency. In this case, σ and m may be employed as the parameters representing the space frequency characteristic which in turn represents the characteristic of enlargement or the characteristic of contraction as shown in Figures 70A and 70B.